# Integrating concepts and indicators for a more effective assessment of High Nature Value Forests

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Todas as correções determinadas pelo júri, e só essas, foram efetuadas.
O Presidente do Júri,

Porto, ______/______/_________

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# Abstract

Over the last years, anthropogenic impacts led to unprecedented biodiversity loss. In order to halt biodiversity loss and the degradation of ecosystem services (ES), several programs and legal instruments were devised and implemented. Rural Development Programs converge with legal instruments for EU environmental sustainability, namely by targeting High Nature Value (HNV) farming and forestry systems in the countryside. To achieve this objective, Member states (MS) are requested to assess the extent and state of HNV areas. However, the lack of a common framework and suitable data, with adequate spatial and temporal resolution, hamper the EU's ability to accurately identify such areas throughout rural landscapes.

This study aimed to contribute to the assessment of High Nature Value forests ($HNV_{forests}$) in the EU, while exploring the potential link between the natural value of such forests and the provision of ecosystem services. Two case-studies were, thus, devised: an initial literature analysis to disclose potential indicators for a spatially-explicit assessment of HNV forests; and a second one, in which a previously described methodological approach to assess HNV farmlands was adapted and implemented to devise the nature value of forests.

In the first case-study, a systematic literature search sought to include scientific publications focusing on indicators that could potentially be used to assess the extent and condition of HNV forests. A total of 38 indicators expressing forest naturalness and/or habitat quality were identified and grouped within 5 distinct categories: Landscape, Composition, Structure, Management and Environmental indicators. Results depicted that Structure and Landscape indicators were more commonly used in the assessment of forests natural value. Further, out of the 38 indicators identified, 21 were used in research tackling the assessment and/or quantification of ES in forest ecosystems, particularly regulating and cultural services. Most of the indicators used in the assessment of ecosystem services expressed structural features of forests. Results also show that the prevalence of indicators seems to be more influenced by the facility to access datasets. Through analysis of literature, a link between the nature value of forests and the wider provision of ecosystem services was apparent. Yet, it is essential to scrutinize this potential correlation by developing tailored research on the relation between forest multi-functionality and the provision of ES.

Built on the literature analysis, the second case-study focused on the adaptation and implementation of a previously described approach devised to assess the nature value of farmlands, to $HNV_{forests}$. Using as illustrative area the Rio Vez watershed, located in

northern Portugal, such framework was implemented using indicators expressing different forest dimensions including landscape, management and patch structure and composition. The coincidence of $HNV_{forests}$ with Natura 2000 and other protection status in the targeted area was also analysed to scrutinize the potential of $HNV_{forests}$ to contribute to support high levels of biodiversity. The application of the framework allowed the identification of three distinct clusters of civil parishes within Rio Vez watershed. These clusters differed in terms of patch size, edge regularity, accessibility and consequently forest naturalness. Analysis of the coincidence of $HNV_{forests}$ with Natura 2000 and other protection instruments showed that the majority of $HNV_{forests}$ are outside protected areas. Such results suggest that such forests may contribute for biodiversity conservation and the provision of ecosystem services in the EU countryside, thus contributing to meet societal demands on environmental sustainability and EU's ambitious goals. Yet, it is essential to further understand the drivers underlying the nature value of such forests. While this case-study contributed to advance the assessment of HNV $HNV_{forests}$ in Europe, more research is needed, namely by testing other indicators (with higher thematic and spatial resolutions) and by targeting other different socio-ecological contexts. When coupled with different land-use scenarios, this methodological approach may provide key information regarding the impact of political decisions on biodiversity and ecosystem service provision in rural Europe.

Finally, a general discussion and implications for the conservation of $HNV_{forests}$ in the context of EU environmental goals are presented.

**Key-words:** High Nature Value Forests, Rural Development Policies, Ecological Indicators, Forest Naturalness, Ecosystem Services Provision.

# Resumo

Nos últimos anos, diversas pressões antropogénicas levaram a crescentes perdas de biodiversidade. De forma a travar a perda de biodiversidade e a degradação dos ecossistemas, diversos programas e instrumentos legais foram implementados na União Europeia. No contexto dos vários instrumentos legais desenvolvidos e implementados na União Europeia tendo como objetivo a sustentabilidade ambiental, as Políticas de Desenvolvimento Rural realçam a importância de práticas de gestão agrícolas e florestais específicas, de baixa intensidade, enquanto promotoras da biodiversidade e da provisão de múltiplos serviços de ecossistemas. Neste contexto, a avaliação e monitorização de áreas rurais de elevado valor natural sido encorajada pela União Europeia. No entanto, a inexistência de uma metodologia comum, e a escassez de bases de dados de adequada resolução temática, espacial e temporal têm limitado esta tarefa.

Este estudo tinha pretendia contribuir para a identificação de florestas com elevado valor natural na Europa, explorando a ligação potencial entre estas florestas e o fornecimento de serviços de ecossistemas. Tendo esse objetivo, dois casos de estudo foram desenvolvidos: o primeiro consistiu numa análise bibliográfica para a identificação de potencias indicadores, espacialmente-explícitos, para o mapeamento do valor natural das florestas; e um segundo, em que uma abordagem metodológica previamente descrita para avaliação e mapeamento do valor natural em áreas agrícolas foi adaptada e implementada a áreas dominadas por floresta.

A revisão bibliográfica realizada no primeiro caso de estudo incluiu publicações científicas em que foram utilizados indicadores refletindo vários componentes da naturalidade das mesmas. No total, 38 indicadores foram identificados e classificados em 5 grupos distintos (previamente definidos): paisagem, composição, estrutura, gestão e ambientais. Verificou-se que os indicadores de estrutura e paisagem são os mais comummente utilizados para a avaliação da naturalidade florestal. Dos 38 indicadores identificados verificou-se que 21 (maioritariamente indicadores de vários aspetos da estrutura florestal) são também utilizados na avaliação e quantificação de serviços de ecossistema, nomeadamente serviços de regulação e culturais. Os resultados obtidos revelam que a prevalência destes indicadores parece ser mais influenciada pela sua disponibilidade (no que diz respeito ao acesso). Apesar dos resultados sugerirem uma ligação entre o valor natural e o aprovisionamento de serviços de ecossistemas, é necessário aprofundar o conhecimento científico existente nesta área por forma a compreender e demonstrar a natureza multifuncional destas.

Após análise bibliográfica, o segundo caso de estudo consistiu na adaptação e implementação de uma abordagem metodológica previamente publicada para a identificação e mapeamento de paisagens florestais de elevado valor natural. Utilizando como área de este a bacia do Rio Vez, localizada no norte de Portugal, o mapeamento consistiu na utilização de conjuntos de indicadores refletindo as várias dimensões de naturalidade das florestas, nomeadamente, paisagem, gestão e estrutura e composição das parcelas florestais. Após mapeamento das áreas florestais de elevado valor natural, a coincidência entre estas e áreas da rede Natura 2000 ou com outros estatutos de proteção na área de estudo foi avaliada para que se pudesse examinar o potencial contributo destas florestas para a manutenção da biodiversidade. A aplicação desta abordagem metodológica permitiu a identificação de três grupos de freguesias distintos na área de estudo. Estes três grupos diferiam no que toca ao tamanho das manchas de paisagem, regularidade das margens, acessibilidade, e consequentemente, no que toca à naturalidade florestal. A coincidência entre florestas com elevado valor de naturalidade com áreas incluídas na rede Natura 2000 ou com outros estatutos de proteção permitiu constatar que a maioria destas florestas estão situadas em áreas sem qualquer estatuto de proteção. No entanto, estas florestas têm elevado potencial para contribuir para os objetivos ambiciosos definidos pela União Europeia no que diz respeito à conservação da biodiversidade e aprovisionamento de serviços de ecossistema. Apesar desta metodologia constituir um avanço para a avaliação da extensão de florestas com elevado valor natural na Europa, é ainda necessário testar a robustez dos indicadores selecionados e testar a abordagem noutros contextos socio-ecológicos. Quando integradas na análise de diferentes cenários de uso do solo, esta metodologia pode apoiar na tomada de decisões políticas relacionadas com a conservação da biodiversidade e serviços de ecossistemas.
Por fim, apresenta-se uma discussão geral, em que incluem implicações dos resultados para a conservação de florestas com elevado valor natural no contexto dos objetivos ambientais da União Europeia.

**Palavras-chave:** Florestas com Elevado Valor Natural, Políticas de Desenvolvimento Rural, Indicadores Ecológicos, Naturalidade Florestal, Aprovisionamento de Serviços de Ecossistemas

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# List of Acronyms

| | |
|---|---|
| **ANC** | Areas with Natural Constraints |
| **CAP** | Common Agricultural Policy |
| **CBD** | Convention on Biological Diversity |
| **CMEF** | Common Monitoring and Evaluation Framework |
| **DEM** | Digital Elevation Model |
| **ED** | Edge Density |
| **EEA** | European Environment Agency |
| **ES** | Ecosystem Services |
| **EU** | European Union |
| **FARM** | Farmland |
| **FAO** | Food and Agriculture Organization of the United Nations |
| **FOR** | Forest |
| **GIS** | Geographic Information System |
| **HNV** | High Nature Value |
| **$HNV_{forest}$** | High Nature Value forest |
| **$HNV_{forest}MAX$** | High Nature value forest Maximum |
| **$HNV_{forest}MIN$** | High Nature Value forest Minimum |
| **$HNV_{forests}$** | High Nature Value forests |
| **LFA** | Less Favoured Areas |
| **MCPFE** | Ministerial Conference on the Protection of Forests in Europe |
| **MEA** | Millennium Ecosystem Assessment |
| **Mean DIST** | Mean Distance between Urban and Forest Patches |
| **Mean S** | Mean Slope |
| **MPS** | Mean Patch Size |

| | |
|---|---|
| **MS** | Member States |
| **MSI_F** | Mean Shape Index of Forest Patches |
| **NFI** | National Forest Inventory |
| **NIWT** | National Inventory of Woodlands and Trees |
| **RDP's** | Rural Development Programmes |
| **SEI** | Shannon Evenness Index |
| **SFM** | Sustainable Forest Management |
| **TEEB** | The Economics of Ecosystems and Biodiversity |
| **UAA** | Utilized Agricultural Area |
| **URB** | Urban |

# Chapter I. Introduction

## 1.1. Worldwide *environmental change and the biodiversity crisis beyond 2010*

Biodiversity is defined as the variability within living organisms and the ecological complexes in which they are incorporated, including the diversity within species, between species and of ecosystems (CBD, 1992). Biological diversity is fundamental for the provision of ecosystem services (ES) and goods, the former defined as the benefits that ecosystems provide to humans. These services are generated by the natural capital through natural processes and are fundamental for the support of human activities and ultimately for human well-being (MEA, 2005).

Ecosystem services (ES) are divided in four categories: provisioning (provision of food, fresh water), regulating (climate, water and disease regulation), cultural (spiritual and religious, aesthetic, educational) and support (soil formation, primary production) (MEA, 2005; Figure 1). Alterations in ES provision affects human well-being due to its impact on security, quality of life, and social and cultural relations. However, over the last years, climate change, over-exploitation of natural resources, biological invasions, pollution and alterations in land-use, that led to the fragmentation and loss of natural areas, have resulted in global biodiversity loss at an unprecedented rate (Chapin III *et al.*, 2000, Diaz *et al*., 2006, Pereira *et al*., 2010, Pimm *et al*., 1995, Sala, 2000). Biodiversity loss is defined as a decrease in relative abundance of species in a biome (Cardinale *et al*., 2012). This loss affects ecosystem properties, mainly in terms of their structure and function (Cardinale *et al*., 2012), and ultimately their resilience (Mori, 2016) resulting in the decrease of ES provisioning (Chapin III *et al*., 2000, Diaz *et al*., 2006).

The current biodiversity crisis, affects directly ES provisioning reflected as the reduction of food, fuel and primary material sources (Chapin III *et al*., 2000) but also indirectly, through the disruption of the natural ecosystem processes (Diaz *et al*., 2006). This is particularly relevant in poor and rural areas as it threatens the quality of life of the highly vulnerable resident populations (Diaz *et al*., 2006).

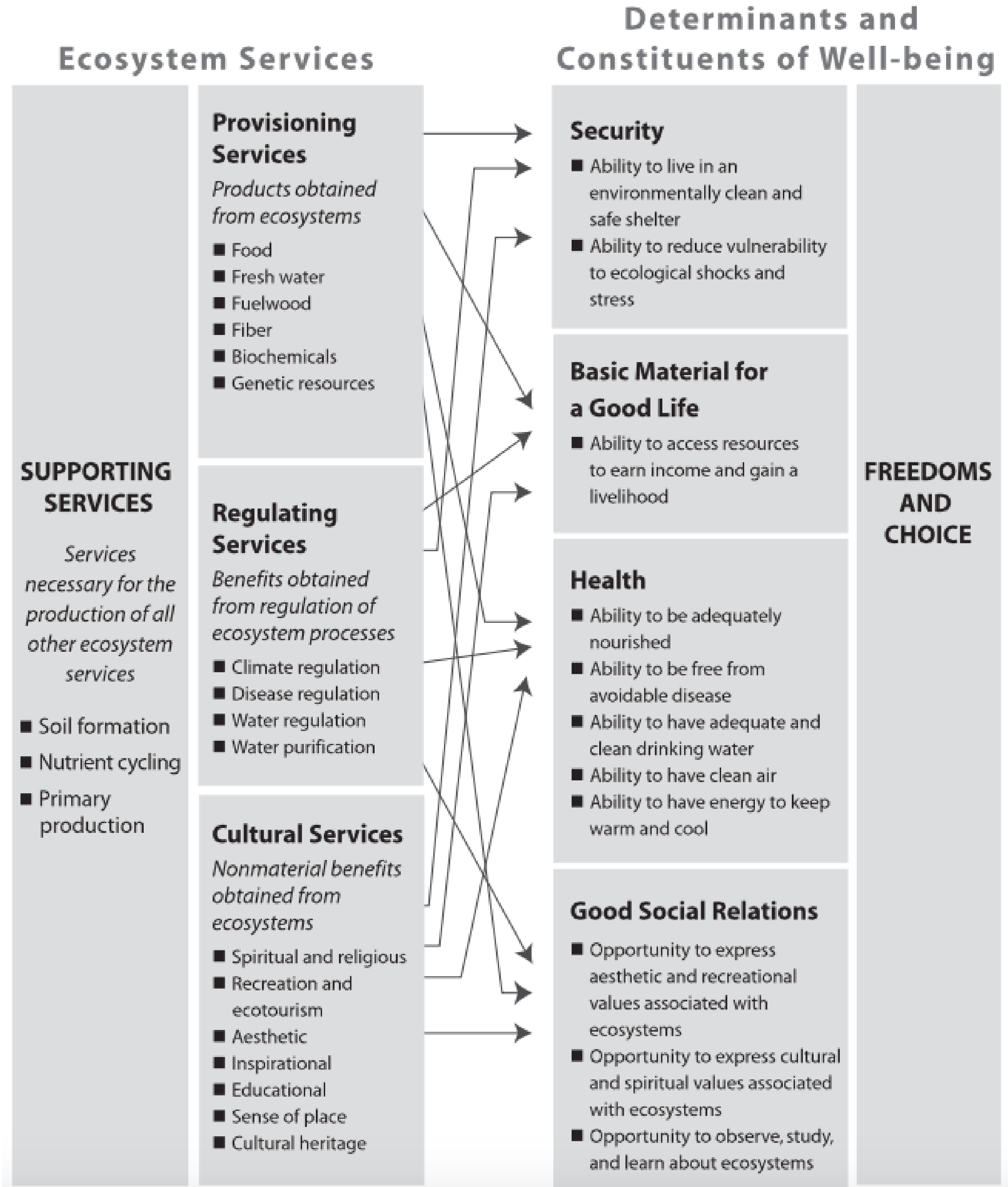


**Figure 1:** Ecosystem services reflect the benefits that ecosystems provide to humans. Four types of ecosystem services have been considered: provisioning, regulating and cultural services, which depict benefits directly obtained by people, and supporting services which are those needed for the maintenance of the other ecosystem service types. Alterations in ecosystem service provisioning affect human well-being due to its impact on security, quality of life, and social and cultural interactions. Adapted from MEA, 2005.

The importance of ecosystem services led both ecologists and economists to conceptualize and propose approaches to quantify these impacts namely by attributing them a monetary value (*e.g.* direct valuation of market prices, estimation of what individuals are willing to pay to maintain service provision; Chapin III *et al*., 2000).

In order to halt biodiversity loss and the degradation of ecosystems, several programs and legal instruments have been recently designed and implemented. One of the major instruments that aimed to bring attention to the current biodiversity crisis and to the importance of biological diversity for human well-being is the Convention on Biological Diversity (CBD). According to the CBD biodiversity is *'the variability among living organisms from all sources including inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems*' (CBD, 1992). The CBD was established in 1992 with three primary objectives: 1) the conservation of biological diversity, 2) the sustainable use of its components; and, 3) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources (CBD, 1992). With these objectives in mind, 10 years after the signature of the CBD, the parties vowed to 'achieve, by 2010', a significant reduction of the current rate of biodiversity loss at the global, regional and national levels as a contribution to poverty alleviation and to benefit 'all life on earth' (Decision VI/26; CBD Strategic Plan). Even though conservation efforts increased, pressures resulting from human actions led to the continuous decrease of biodiversity worldwide (Butchart *et al*., 2010, Walpole *et al*., 2009, SCBD, 2010) (Figure 2). After the non-achievement of the 2010 target, the CBD developed a new strategic plan that aimed to 'take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication'. To reach such goals, the reduction of pressures, the restoration of ecosystems and the sustainable use of resources are essential.

In Europe, human-induced fragmentation led to the degradation of European ecosystems, the loss of several species and the decline in the abundance of others (COM (2010) 4). In order to prevent further loss, besides contributing to the CBD targets, the European Union (EU) committed 'to halt the decline of biodiversity [in the EU] by 2010' and to 'restore habitats and natural systems' (COM (2006) 216). To achieve such goals, efforts have been invested so that the Birds and Habitats Directives and the Natura 2000 network contribute to preserve and enhance the conservation status of the most important habitats and species within the EU territory.

The ineffectiveness of the applied measures led the EU to implement a new conservation strategy (COM (2011) 244). The EU2020 strategy aims to halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them as far as feasible, while stepping up the EU contribution to averting global biodiversity loss' (COM (2011) 244). To achieve these goals several initiatives were developed and implemented, namely The Economics of Ecosystems and Biodiversity, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Service (TEEB), that showcase the important benefits provided by ecosystems and biodiversity and the high cost of the biodiversity loss and the ecosystem degradation.


**Figure 2.** Current development of the headline biodiversity indicators within the Convention on Biological Diversity framework. Colours depict the status of development and implementation of each indicator included, as follow: ■□Fully developed with well-established methodologies, ■□under development, and ■□not being developed. Multiple labels indicate multiple measures under each headline. Adapted from Walpole *et al*., 2009.

## 1.2. Forest habitats: from support to biodiversity to the provision of multiple services

The Food and Agriculture Organization of the United Nations (FAO) defines forests as 'land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*' (FAO, 2015). According to the canopy cover, two types of forests can be defined: open forests, corresponding to values of canopy cover ranging between 10 and 40 %; and, closed forests, characterized by values of canopy cover higher than 40% (Shvidenko *et al*., 2005). Other differences observed in forest ecosystems across the world are due to changes regarding latitude, temperature, rainfall patterns, soil composition and disturbance by human activity (UNEP, 2009).

Worldwide, forests represent 31% of the terrestrial land and are among the most valuable ecosystems (EEA, 2015). These ecosystems account for more than 80% of the world's terrestrial biomass harbouring over half of the world's terrestrial plant and animal species representing an important repository of terrestrial biodiversity (Aerts and Chapin, 2000, Aerts and Honnay, 2011, Shvidenko *et al*., 2005). Besides support to biodiversity, forests provide ecosystem services (*e.g.* timber, food and fresh water provision, climate and water regulation, natural risk mitigation; Table 1) that most of the human population depends on, either for their livelihood or for their well-being (European Commission, 2003, FAO, 2006, Jacek *et al*., 2005).

**Table 1.** Ecosystem services that have been related to forests presented by type, following the Millennium Ecosystem Assessment classification (MEA, 2005).

| *ES Type* | *ES* | *Service description* | *References* |
|---|---|---|---|
| Provision | Timber | Wood used for different purposes | Croitoru, 2007, Duncker *et al*., 2012, EEA, 2015 |
| | Fuel | Wood, dung, and other biological materials used as energy sources | Croitoru, 2007, Duncker *et al*., 2012, EEA, 2015 |
| | Fiber | Materials such as wood, jute, hemp and silk | Croitoru, 2007, Duncker *et al*., 2012, EEA, 2015 |

**Table 1. (cont.)**

| | | | |
|---|---|---|---|
| | Fresh water | Forests and vegetation cover influence water availability | FAO, 2013 |
| | Food | Forests provide a range of wild foods derived from plants, animals and microbes | Croitoru, 2007, EEA, 2015, Ferraro *et al*., 2011, Vihervaara *et al*., 2010 |
| | Genetic resources | Genes and genetic information used in biotechnology | Croitoru, 2007, EEA, 2015, Ferraro *et al*., 2011, Vihervaara *et al*., 2010 |
| Regulation | Erosion control | Vegetation is fundamental in soil retention and in the prevention of landslides | Greenwood *et al*., 2004, Reubens *et al*., 2007, FAO, 2008 |
| | Climate regulation | Ecosystem function affects climate as they influence rainfall | Crowther *et al*., 2015, Duncker *et al.*, 2012, Hansen *et al.*, 2013 |
| | Water regulation | Changes in land cover influence runoff, flooding and aquifer recharge | Aust and Blinn, 2004, FAO, 2008 |
| | Air and water purification | Trees and other plants can remove pollutants form air and water | Crowther *et al*., 2015, Duncker *et al.*, 2012, Hansen *et al*., 2013 |
| | Soil quality maintenance | Forest ecosystems supply the soil with nutrients maintaining soil quality | Crowther *et al*., 2015, Duncker *et al.*, 2012, Hansen *et al*., 2013 |
| | Natural risk mitigation | Forests serve as buffers against natural disasters preventing possible damage | FAO, 2013 |
| | Carbon storage | Tree and plant growth results in the removal of atmospheric carbon dioxide incorporating it in their tissue | Crowther *et al*., 2015, Duncker *et al*., 2012, Hansen *et al*., 2013, Miura *et al*., 2015 |
| | Natural pest control | Ecosystems regulate the prevalence of pests and diseases through the activity of predators and parasites | Nasi *et al*., 2002 |
| | Pollination | Ecosystems affect the distribution, abundance, and effectiveness of pollinators | Nasi *et al*., 2002, Vihervaara *et al*., 2010 |
| Cultural | Cultural diversity | Ecosystem diversity influences cultural diversity | European Union, 2014 |

**Table 1. (cont.)**

| | | | |
|---|---|---|---|
| | Spiritual and religious values | Some religions attribute spiritual and religious value to ecosystems | European Union, 2014 |
| | Educational values | Ecosystems provide a basis for formal and informal education | European Union, 2014 |
| | Cultural heritage values | Societies value the maintenance of historically important landscape and species | European Union, 2014 |
| | Recreation and Ecotourism | People often chose to spend leisure time in landscapes with more natural characteristics | Nasi *et al*., 2002, Pichler and Sorokova, 2005 |
| | Aesthetic value | People find aesthetic value in various aspects of natural ecosystems | Vihervaara *et al*., 2010 |
| <u>Support</u> | Nutrient cycling | Trees and other plants contribute to nutrient cycling | Harmon *et al*., 1986, Vihervaara *et al*., 2010 |
| | Soil formation | Forests contribute with organic matter in the process of soil formation | Petter *et al*., 2013, Vihervaara *et al*., 2010 |

Whilst forests have been acknowledged as essential ecosystems at a global level (*e.g.* Hansen *et al*., 2013, Hassan *et al*., 2005, Pan *et al*., 2011), they are also amongst the most threatened (FAO, 2016, UNEP, 2009). The loss of natural and semi-natural forest areas resulted in a decrease in biodiversity and ecosystem service provision (FAO, 2002, Laurance, 2007, SCBD, 2009). In order to prevent further losses, sustainable forest management (SFM) has been encouraged at a global scale (EC, 2003, ITTO, 2006).

Europe is one of the richest sub-region as forests represent ca. 36 % of the continents area. However, this continent is also the one with the least amount of natural forests (ca. 3%; (Bengtsson *et al*., 2000). Deforestation in the continent has resulted in a significant loss of forest areas in the last 200 years. However, since the 1990's forest area has been stable or increasing in European countries (EEA, 2015), with gained area mostly being managed under intensive forestry practices. Such forestry practices are driving the loss of forest biodiversity and related ecosystem services (Bengtsson *et al*., 2000). This is especially relevant in rural areas where over 50% of the population are, directly or indirectly, dependent on these ecosystems (Byron and Arnold, 1999).

## 1.3. High Nature Value forests in the EU countryside

### 1.3.1. What are HNV forests and why are they important

Traditionally managed landscapes, including farmlands and forests, are normally associated with certain functional and spatial features such as low productivity, high biodiversity, remoteness and decreasing and aging population (OECD, 1994).

The European countryside (ca. 92% of the European territory; Council Decision 2006/144/EC) is characterized by a great diversity and richness of cultural landscapes resulting from a complex combination of natural and anthropogenic factors (Bugalho *et al.*, 2011, Fischer *et al.*, 2012, Mücher and Wascher, 2007). Even though the majority of such areas had production as a main purpose in the past, they also produced a series of externalities (Vos and Meekes, 1999), including biodiversity support (Hampicke, 2006) and the provision of different ecosystem services. These services range from the provision of goods including food and water (Hartel *et al.*, 2014, Ma and Swinton, 2011, Ooba and Hayashi, 2014) to climate and water regulation, soil formation and primary production (Ma and Swinton, 2011, Ooba and Hayashi, 2014). Overall, cultural landscapes have invaluable historical, aesthetical and recreational importance (Mitchell and Buggey, 2000, Palang *et al.*, 2005, Plieninger and Bieling, 2012). Traditional European landscapes are fundamental for the quality of life of European Union (EU) communities (Palang et al., 2005), even though current intensification and abandonment trends hinder the maintenance of intermediate disturbance levels that these ecosystems depend on (Bugalho *et al.*, 2011, Fischer *et al.*, 2012).

In order to prevent further losses of such landscapes, the Rural Development Policy was established as the 2nd pillar of the Common Agriculture Policy (CAP) in 2000 with the purpose of meeting economic, environmental and social challenges in European rural areas by focusing on "promoting knowledge transfer and innovation" "in the in the agriculture, food and forestry sectors" (axis 1) and on the improvement of the environment and countryside through the provision of "measures to protect and enhance natural resources, as well as preserving high nature value farming and forestry systems and cultural landscapes in Europe's rural areas" (Council Decision 2006/144/EC). The implementation of proposed measures contributes, not only to the protection of these rural areas, but also to the European commitment to halt biodiversity loss by 2020 as well as the water policy framework establishment. Within Rural Development Policies, six EU priorities for rural development were identified (Regulation (EU) No 1305/2013):

1) Fostering knowledge transfer and innovation in agriculture, forestry, and rural

areas;

2) Enhancing farm viability and competitiveness of all types of agriculture in all regions and promoting innovative farm technologies and the sustainable management of forests;
3) Promoting food chain organisation, including processing and marketing of agricultural products, animal welfare and risk management in agriculture;
4) Restoring, preserving and enhancing ecosystems related to agriculture and forestry;
5) Promoting resource efficiency and supporting the shift towards a low carbon and climate resilient economy in agriculture, food and forestry sectors;
6) Promoting social inclusion, poverty reduction and economic development in rural areas.

This research aims to contribute to advance point 4) as it targets High Nature Value areas (Regulation (EU) No 1305/2013).

The High Nature Value (HNV) concept was initially devised in the 1990's to recognise the link between extensive management practices and biodiversity levels in EU farmlands (Baldock *et al*., 1993) and later extended to incorporate forest areas due to their role in biodiversity support as well as ecosystem goods and services provision (IEEP, 2007).

HNV areas exhibit certain physical structure, composition, management and landscape characteristics that support high biodiversity levels and production of a series of Ecosystem services (ES) and goods (Baldock *et al*., 1993, Beaufoy *et al*., 1994).

Overall, three main criteria were identified to define HNV areas: 1) Intensity of land-use, 2) Presence of semi-natural features and 3) Presence of a land use mosaics (IEEP, 2007, Pignatti *et al*., 2012). In the case of HNV farmlands, they are coincident with agriculture dominated areas where practices support or are associated with high diversity of species and habitats and/or the presence of species of European, national or regional concern (Baldock *et al*., 1993, Beaufoy *et al*., 1994). HNV forests ($HNV_{forests}$) have been defined as natural and semi-natural forests in Europe where historical or current management supports a high diversity of native species and habitats, and/or those forests which support the presence of species of European, and/or national/regional conservation concern (IEEP, 2007). Overall, this definition largely builds on forest naturalness defined as 'the similarity of a current ecosystem state to its natural state' (Winter, 2012). Forest naturalness depends on the level of anthropogenic intervention, and thus HNV forests have been classified according to management intensity. Historical management regime alters forests composition, structure and function and consequently affects biodiversity support and the provision of ES (IEEP,

2007). As management regime affects composition, unmanaged and extensively managed forests have a closer-to-natural composition. Landscape diversity is also important for HNV forest areas as a more diverse landscape is a favourable characteristic for biodiversity levels.
Three forest categories are distinguished according to forest naturalness: naturally dynamic forests, semi-natural forests and plantation forests (Table 2).

**Table 2.** Different forest categories according to their naturalness and their relation with High Nature Value (EENRD, 2009).

<table>
<tr><th>Forest type</th><th>Description</th><th>HNV Status</th></tr>
<tr><td><u>Plantations</u></td><td>Stands established after afforestation or reforestation processes. Composed by introduced species or intensively managed stands of indigenous species. Plantations of indigenous species are even aged stands of one or two species and regular spacing, excluding plantation stands that haven't been intensively managed for a significant period of time.</td><td rowspan="2">Not HNV</td></tr>
<tr><td rowspan="2"><u>Semi-Natural</u></td><td rowspan="2">Non-plantation forests whose structure, composition and functions have been modified by anthropogenic activities.</td></tr>
<tr><td rowspan="2">HNV Forests</td></tr>
<tr><td><u>Naturally Dynamic</u></td><td>Forests whose composition and function have been shaped by the dynamics of natural disturbance regimes without substantial anthropogenic influence over a long time period.</td></tr>
</table>

Naturally dynamic forests are the least altered by anthropogenic factors and, therefore, considered as HNV forests. Semi-natural forests are considered HNV forests or not depending on the historical management and whether or not that management mimics natural processes and includes traditional practices that promote high biodiversity levels. Lastly, plantation forests are normally intensively managed and consequently not consider as exhibiting HNV.

### 1.3.2. HNV forests assessment across the EU

Rural Development Policies aimed to contribute to the restoration, preservation and enhancement of ecosystems related to agriculture and forestry focusing on areas facing natural constrains and HNV areas were pinpointed as one of the union priorities for rural areas (Regulation (EU) No 1305/2013).

In order to achieve Rural Development Policy objectives, it was necessary to assess the extent and state of HNV areas which in turn led to the need of indicators that allowed their identification in each Member State (MS). For this purpose, the European Commission envisaged three indicators from the Common Monitoring and Evaluation Framework (CMEF), including a Baseline Indicator, a Result Indicator and an Impact Indicator (Table 3).

**Table 3.** Common Monitoring and Evaluation Framework High Nature Value Indicators (EENRD, 2009)

| **Indicator Number** | **Indicator Title** | **Measurement** |
|---|---|---|
| Baseline Indicator 18 | Biodiversity: High nature value farmland and forestry | Utilized Agricultural Area (UAA) of HNV Farmland, hectares |
| Result Indicator 6 | Area under successful land management contributing to biodiversity and HNV farming / forestry | Total area of HNV farming and forestry under successful land management, hectares |
| Impact Indicator 5 | Maintenance of HNV farmland and forestry | Changes in HNV farmland and forestry defined in terms of quantitative and qualitative changes. |

To develop and apply the CMEF HNV impact indicator it is necessary to first describe and characterize the different types of HNV forests. Besides that, it is also necessary to develop indicators that allow the identification of these areas (EENRD, 2009). This task has, however, been made difficult by the complexity of existing HNV systems.

These indicators are supposed to be reported at national and/or regional levels to monitor the extent, condition and dynamics of HNV farming and forestry landscapes. Therefore, there is the need of quantitative indicators that provide information on changes in the extent of HNV areas as well as qualitative indicators that provide information on changes in their conditions (IEEP, 2007).

Although some indicators have been proposed for the assessment of HNV forests, the identification and mapping of these areas hasn't been as successful as the mapping of the HNV farmlands (EEA, 2014). This inability is linked with the complexity of their definition as well as the absence of a standardized methodological framework. The difficulty in finding appropriate indicators that can be used throughout the different forest types present in European territory in broader, regional scales has also contributed to the lack in published scientific literature regarding this subject (Petrontino and Fucilli, 2013). Also contributing for these limitations is the lack of spatial Europe-wide information regarding indicators that can be helpful in the mapping of these areas (IEEP, 2007).

Nevertheless, methodological frameworks have been proposed to tackle this challenge.

Among them Dimalexis *et al*. (2008), used different indicators in a GIS environment to target natural and semi-natural forests likely to exhibit High Nature Value. Although they obtained useful results, the lack of current data available at the time the study was pinpointed as a major drawback due to the occurrence of several forest fires between the collection of the data and the realization of the study. Other frameworks build on the joint application of indicators defined during the Ministerial Conference on the Protection of Forests in Europe (MCPFE) and National Forest Inventory (NFI) to assess the extent of the HNV forests at national level (Pignatti *et al*., 2012). Even though the combination of NFI and MCPFE indicators has proven to be effective in the assessment of HNV forests *per* district, this study does not include the mapping of these areas (Pignatti *et al*., 2012).

Another methodological approach was described by Petrontino and Fucilli (2013). Overall, these authors proposed the identification of HNV forests at a regional scale of areas by using a wide variety of indicators with different weights. These indicators have been ranked by field experts (*e.g.* academic and research institutes, regional services, environmental associations) according to their contribution to forest naturalness and consequently service provision. The Scottish Government (2011) has also published a methodology proposal using indicators derived from their National Inventory of Woodlands and Trees (NIWT). In this report they distinguish three different forest types and indicators that could be used in the assessment of those areas.

Besides the aforementioned approaches, the European Environment Agency (EEA) published a report where a methodological approach for the identification of forests with high nature value is proposed (EEA, 2014). However, this report focuses only on beech forests.

Even though some of these approaches appear to be effective in the assessment of HNV forests, there's no common methodology, and no convergence in the used indicators and scale, paired with the absence of spatially-explicit results, which hamper the ability of using such frameworks at the European level.

## 1.4. Objectives and thesis structure

The overarching goal of this research is to contribute to the assessment of High Nature Value forests in Europe, while exploring the potential link between the nature value of such forests and the provision of multiple ES in the EU countryside. Understanding how the nature value of extensively managed forest ecosystems may be assessed and mapped is expected to provide tools to support their maintenance and enhancement in rural areas, thus contributing to achieve EU ambitious environmental goals. By linking such assessment to the potential provisioning of ES in multifunctional forests, this research is expected also to advance knowledge on how such areas may be viable in the future, from a socio-ecological viewpoint.

To achieve such goals, the following specific goals were pursued:

i) Identification of indicators commonly used in the scientific arena to assess forest naturalness and/or habitat quality;
ii) Analysis of the putative relationship between the nature value of the targeted ecosystems and the potential provision of ES beyond support for biodiversity;
iii) Conceptualization of a methodological framework, build on multiple sets of spatially-explicit indicators, to support the assessment of High Nature Value forests ($HNV_{forests}$) in the EU countryside; and,
iv) Implementation and test of the proposed framework within an illustrative area in the Northwestern Portugal (Region of the Rio Vez Watershed), linking such assessment to a preliminary analysis of HNV forests potential to provide support of biodiversity (link with ES).

Overall, this thesis includes four chapters. First, the research topic is framed within an introductory chapter (Chapter I), where an overview on biodiversity and ecosystem services is provided, then converging to specificities regarding the High Nature Value forests concept. HNV forests relation to former and current Rural Development Programs (RDP's; Regulation (EU) No 1305/2013) are tackled, and main caveats for the assessment of such forests across the EU scrutinized.

Chapter II and III include the two studies developed in this research program. The first one (Chapter II) focuses on the identification of different indicators that can potentially be useful in the assessment of $HNV_{forests}$ and in the analysis of the relationship between nature value and ES provision. With the conduction of this study we aim to find commonly used, spatially-explicit indicators that can potentially be used in the assessment of $HNV_{forests}$ and link indicators of forest naturalness with their potential for the provisioning of ES. To do so a systematic literature search focusing on indicators used in the assessment of forest naturalness and/or habitat quality as well as the coincidence between these and indicators used in the mapping of ES was implemented and all suitable references were later analysed. The extent of different kinds of indicators in the assessment of forest naturalness and mapping was then analysed and discussed in the context of $HNV_{forest}$ assessment. Building on results from Chapter II, in Chapter III a methodological framework to assess $HNV_{forests}$ is proposed and tested. Implementation of such framework was done in a rural area in northern Portugal. With the realization of this study we aimed to develop a multi-criteria methodological framework that can be used in the assessment of $HNV_{forests}$ throughout Europe through the use of a range of reliable indicators based on key characteristics (landscape, management practices and biodiversity values). Preliminary results for $HNV_{forests}$ assessment were then analysed to ascertain the potential of such forests to support high levels of biodiversity.

Finally, in Chapter IV a general discussion is presented, in which results obtained for both case studies are discussed in the context of $HNV_{forests}$ assessment in the EU. Implications from preliminary results for the conservation of such forest ecosystems are drawn in the context of EU ambitious environmental goals, and perspectives for future research highlighted.

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# Chapter II. Linking high nature value forests and the potential for ecosystem services provisioning

**Abstract**

The role of extensively managed forests for the maintenance and enhancement of environmental sustainability in the European Union countryside has been claimed. In the late 90's the concept of High Nature Value (HNV) was devised to acknowledge the pivotal role of extensive farming, and late, forest practices to the preservation of biodiversity in Europe. Overall, HNV forests are defined as natural and semi-natural forests where management practices (historical or present) support high levels of native species and habitats, and/or where forestry practices support the presence of species of European, and/or national, and/or regional conservation concern. The assessment of $HNV_{forests}$ extent and condition in member states was among the former objectives of the EU Rural Development Programs. However, the diversity of forest types within Europe, the lack of spatial data, and the lack of common framework hinder the assessment of these areas throughout Europe.

Here, we aimed to contributed to the identification of forest naturalness and/or habitat quality indicators as well as analyse the putative link between indicators expressing the nature value of forest ecosystems and their potential provision of ES beyond biodiversity support.

A systematic literature search sought to include all scientific publications focusing on indicators that could potentially be used to assess the extent and condition of HNV forests. A total of 38 indicators expressing forest naturalness and/or habitat quality were identified and grouped within 5 distinct categories: Landscape, Composition, Structure, Management and Environmental indicators. Results depicted that Structure and Landscape indicators were more commonly used in the assessment of forests natural value. Further, out of the 38 indicators identified, 21 were used in research tackling the assessment and/or quantification of ES in forest ecosystems, particularly regulating and cultural services. Most of the indicators used in the assessment of ecosystem services expressed structural features of forests. Results also show that the prevalence of indicators seems to be more influenced by the facility to access datasets. Through analysis of literature, a link between the nature value of forests and the wider provision of ecosystem services was apparent. Yet, it is essential to scrutinize this potential correlation by developing tailored research on the relation between forest multi-functionality and the provision of ES.

**Keywords**

Rural Development Programmes, High Nature Value Forests, Ecosystem Services, Indicators, Forest Naturalness

## 2.1. Introduction

Worldwide, forests constitute one of the dominant land-uses, accounting for ca. 30% of the terrestrial area (FAO, 2010). Acknowledged as essential for human well-being, forest ecosystems provide a wide range of woody (timber, fuel and fiber; Croitoru, 2007) and non-woody goods (food, fodder and medicinal resources; Croitoru, 2007). As multifunctional ecosystems, forests also provide a wide range of ecosystem services (ES) (Fuehrer, 2000). They are essential to climate regulation, air and freshwater purification and soil protection (Duncker *et al*., 2012). Furthermore, forests are known for their pivotal role for biodiversity conservation, as they provide habitat for over half of terrestrial plant and animal species (Ozanne *et al*., 2003).

Whilst their overall importance has been widely recognized (*e.g.* Hassan *et al*., 2005), forest ecosystems have been facing increasing threats due to global environmental change. Unsustainable management practices (*e.g.* intensive forest harvesting, Duncker *et al*., 2012); fire (Estreguil *et al*., 2012) and increasing land-use change and consequent habitat loss and fragmentation (SCBD, 2002) paired with climate change (*e.g.* Dale *et al.*, 2001) are among the main drivers underlying biodiversity and ES loss within forest ecosystems. Overall, such changes resulted in the loss of natural and semi-natural forests, and thus in the decrease of habitat quality due to their impacts on stand and landscape structure (*e.g.* connectivity between forest patches) and composition, ultimately reflected on forest naturalness, biodiversity levels and the provision of ecosystem services (FAO, 2002).

In Europe, forests currently account for 36% of its terrestrial area (EEA, 2015). Shaped through time by land owners and managers, the diversity and 'naturalness' of European forests reflect the intertwined character of human and nature in social-ecological systems (EEA, 2006). Forest naturalness has been related to higher levels of biodiversity, which entail more stable and reliable ecosystem functions over time (Winter, 2012), a critical issue for the European territory, where only ca. 3% of natural forest remains undisturbed (Hassan *et al*., 2005). While forest coverage decreased from 80 to 36% in Europe in the last 200 years (excluding the Russian Federation), increasing trends have been reported since the 1990's (EEA, 2015). Such trends reflect farmland abandonment (*e.g.* through natural expansion of forests, but mainly afforestation processes, planting and seedling of trees on land that was not previously forested; EFI, 2000). Most forestry practices impact ecosystems and their functions resulting in the decrease in the provision of certain ecosystem services (Bengtsson *et al*., 2000), specifically in rural areas, where forests constitute important social-ecological systems, which contribute to over 50% of livelihoods (Byron and Arnold, 1999).

Due to the important role of forest ecosystems for biodiversity conservation and ecosystems resilience, European Union (EU) environmental policies have been encouraging sustainable practices and adaptive management in forestry (*e.g.* selective logging, enrichment, human-assisted regeneration; Paquette *et al*., 2009). Combining management practices with environmental services and social benefits has thus been considered strategic in the context of global, regional and local environmental policies (Maes *et al*., 2012). Specifically, maintaining traditional management practices, such as those underlying High Nature Value forests have been highlighted in EU environmental commitments, namely the Common Agricultural Policy (CAP) through Rural Development Programs (RDPs; Council Regulation (EC) No 1698/2005). By promoting sustainable management of farming and forestry systems, RDPs have been contributing to the maintenance of traditional social-ecological systems, mostly located in marginal rural areas of Europe under increasing economic, social and environmental challenges (Council Decision 2006/144/EC).

Devised in the early 90's, the concept of High Nature Value (HNV) aimed to support specific farming and forestry practices known to contribute and support species and habitats within traditional rural landscapes (Beaufoy *et al*., 1994). High Nature Value forests (hereafter $HNV_{forests}$) have thus been defined as natural and semi-natural forests where management practices (historical or present) support high levels of native species and habitats, and/or where forestry practices support the presence of species of European, and/or national, and/or regional conservation concern (IEEP, 2007). As with most forests worldwide, forests in Europe have been subjected to disturbance and for that reason naturally dynamic forests are currently sparse (IEEP, 2007). Also, the area of forests under traditional management practices, known to promote the nature value of (semi)natural forests, has been decreasing. Naturally dynamic forests and forests under traditional management are today mostly found scattered in landscapes where such habitats often persist as small remnants in farmlands (IEEP, 2007).

$HNV_{forests}$ are widespread in the EU countryside, mostly on poorer land where small woodlands are found intermingled with farmlands and intensification has not been possible due to natural limitations (*e.g.* severe climate, presence of steep slopes, unproductive soil), and are thereby less productive than forests under more intensive management (IEEP, 2006). Such areas, known as areas with natural constraints (ANC, previously referred as 'less favoured areas', LFA; Beaufoy *et al.*, 1994), are more prone to abandonment, which has been highlighted among drivers underlying biodiversity loss. Whilst agro-environment schemes targeting HNV areas have been implemented with the intention of preserving ecosystem services provided by ANC's, to support their maintenance in the EU countryside (Regulation (EU) No 1305/2013). However, to assure that $HNV_{forests}$ are economically sustainable in the future, there is a pressing need to understand their economic potential, namely through the link of such forests with the potential provision of multiple ecosystem services and goods (RSPB, 2009). In such context, assessing the extent and condition of HNV areas (both farming and forests) across the EU countryside is essential (IEEP, 2007). However, due to the diversity of forest types within rural landscapes across the EU, the absence of a common approach for mapping and the lack of suitable and robust datasets on relevant indicators, such assessment remains a challenge to tackle (IEEP, 2007).

Recent research has highlighted the need for the development and testing of indicators suitable to inform on the nature value of forests, emphasizing naturalness, *i.e.* the similarity of the current state of an ecosystem to its natural state, and habitat quality as a cornerstone (*e.g.* see Winter, 2012). Nevertheless, the suitability of the majority of the most commonly implemented indicators has seldom been tested as they do not exhibit spatial and/or temporal resolution (EEA, 2014). This study aims to contribute to fill this gap by: i) identifying indicators that have been used to assess forest naturalness and/or habitat quality; and, ii) analyzing the putative relationship between the nature value of targeted ecosystems and the potential provision of ES beyond biodiversity support. We advocate that $HNV_{forests}$ are mostly traditionally managed forests whose multifunctional character underpins their high potential for provisioning diverse ecosystem services and goods, essential to assure their socio-economic sustainability in the future. To tackle such goals, a systematic literature review, built on two-steps, was conducted to identify and analyse possible indicators to assess forest naturalness. In the first step the literature analysis was focused on the identification of spatially-explicit indicators suitable to express distinct dimensions of forest naturalness which may be used for the assessment of $HNV_{forests}$. In the second step the potential link between indicators identified in Step 1 and their usefulness for supporting the assessment of ES in $HNV_{forests}$ was analysed. Results and implications for the maintenance and enhancement of such ecosystems under scenarios of social-ecological change were discussed in the context of $HNV_{forests}$ maintenance and enhancement in the EU countryside.

## 2.2. Literature review and data analysis

A systematic literature analysis sought to include scientific publications focusing on indicators used to assess the extent and condition of $HNV_{forests}$ in the EU countryside, while linking such indicators to research targeting the provision of ES and goods was implemented. However, due to the lack of research studies specifically targeting High Nature Value forests, preliminary results suggested that the analyses should be broaden to other scientific publications targeting forest ecosystems under extensive and/or traditional management.

Overall, a two-step analysis was implemented. The first step (Step 1) aimed at identifying indicators that have been used to assess forest naturalness and/or habitat quality in forest ecosystems. The second step (Step 2) focused on indicators highlighted in Step 1 which have been also used for the assessment of ES in forests.

Literature search was performed initially in March 2015 and again in April 2016 by applying a combination of keywords (See Table 4) in two distinct databases: ISI Web of Science (Step 1: 419 prospective articles, Step 2: 60 prospective articles), SCOPUS (Step 1: 335 prospective articles, Step 2: 126 prospective articles). The following inclusion criteria were considered in Step 1: 1) forest ecosystem type, 2) management practices, 3) published in scientific journals, book chapters, conference proceedings, project reports, comprehensive reviews and governmental reports; 4) published from 1985 onwards; 5) geographic context (Europe) and 6) methodological approach, by including case-studies implementing indicators to assess forest naturalness and/or forest quality. For Step 2, the inclusion criteria included: 1) published in scientific journals, book chapters, conference proceedings, project reports, comprehensive reviews and governmental reports; 2) published from 1985 onwards and 3) methodological approach, by including case-studies implementing indicators to assess ES. A total of 940 cases (754 in Step 1 and 186 in Step 2) were attained from the literature search. Such cases were then analysed for their suitability considering: (1) the title and keywords, (2) the abstract, and (3) the main text. As a result, the number of scientific research studies considered decreased 136 (90 in step 1 and 46 in step 2, respectively). In each phase, publications that fulfilled the inclusion criteria were considered for the following stage of the analysis.

**Table 4.** Combinations of keywords implemented in each Step of the systematic literature search. Step 1 aimed at identifying indicators that have been used to assess forest naturalness and/or habitat quality in forest ecosystems , whilst in Step 2 focused on indicators highlighted in Step 1 which have been also used for the assessment of ecosystem services in forests.

| | |
|---|---|
| **Step 1** | "High Nature Value Forests", "Forest Naturalness"; "Natural Forest", "Old-growth Forest", "Sustainable forest management", "Indicators", "Assessment", "Mapping" |
| **Step 2** | "Forest Ecosystem Services", "Indicators", "Assessment", "Mapping" |

Step 1 aimed to identify indicators expressing forest naturalness and/or habitat quality. In order to simplify the analysis of results, indicators identified during the literature search were classified according to six pre-defined categories: 1) Landscape; 2) Composition; 3) Structure; 4) Management; 5) Environmental; and 6) Others; which are described in detail in Table 5. Classification of indicators in each of the 6 pre-defined categories followed closely the description and usage of each one according to the original sources. Indicators conveying the same information were aggregated under the same category.

A standardized group of information was gathered from each selected article. Data collected included the scale of the study, the spatially-explicit character of the implemented indicators, and specific management type (within sustainable management practices) (Table 6).

**Table 5.** Groups of indicators considered in this research, including their definition and examples.

| **Indicator group** | **Definition** | **Examples** |
|---|---|---|
| Landscape | Indicators informing on landscape-level characteristics, expressed as landscape metrics, composition and structure. | Important bird areas (Maesano *et al*., 2014, Petrontino and Fucilli, 2013), landscape fragmentation (EEA, 2014, Gao *et al*., 2015), landscape patterns (Kovac *et al*., 2016, Petrontino and Fucilli, 2013) |
| Composition (patch-level) | Indicators expressing the composition of forest patches/stands. | Proportion of native trees (Veen *et al*., 2010), species diversity (Petritan *et al*., 2012, Winter, 2012), exotic species (Noss, 1999, Pignatti *et al*., 2012) |
| Structure (patch-level) | Indicators expressing patch/stand structure, | Canopy closure (Coote *et al*., 2013, Gao *et al*., 2015), tree size (Burrascano *et al*., 2008, Kovac *et al.*, 2016), forest age structure (von Oheimb *et al*., 2005), patch structure (Petrontino and Fucilli, 2013) |

| | | |
|---|---|---|
| Management | Indicators reflecting the type or the intensity of forest management practices. | Deadwood (Barbati *et al.*, 2014), forest health (Petrontino and Fucilli, 2013), specially shaped trees (Palo *et al*., 2011), management regime (Petrontino and Fucilli, 2013) |
| Environmental | Indicators disclosing abiotic characteristics of the forest ecosystems. | Elevation (Lombardi *et al*., 2015), precipitation (Neumann and Starlinger, 2001), slope (Burrascano *et al*., 2009, Maesano *et al*., 2014), water availability (Bugalho *et al*., 2016) |
| Others | Group consisting of all single occurrences (indicators mentioned only once across all scientific references). | Guild structure (Stork *et al*., 1997), level of succession (Ode *et al*., 2009), depth of litter (Mendoza and Prabhu, 2003), patterns of mortality (Noss, 1999) |

**Table 6.** Additional information retrieved from original studies retrieved in Step 1.

| | |
|---|---|
| **Scale** | 1) Stand, 2) Landscape, 3) Regional, 4) National, 5) Forest management unit and 6) Not applicable |
| **Management type** | 1) Extensively managed, 2) Sustainably managed, 3) Unmanaged and 4) Not applicable |
| **Spatially-explicit** | 1) Spatially-explicit and 2) Not spatially-explicit |

The second step aimed to highlight which indicators, previously identified in Step 1, have been used for the assessment of ES in forests. References identified in Step 1 were screened and indicators grouped according to classes of ecosystem services, as defined by the Millennium Ecosystem Assessment (MEA, 2005). In short, in the Millennium Ecosystem Assessment (MEA) ES are devised into four categories: supporting, provisioning, regulating, and cultural (MEA, 2005). Supporting services refer to those ES that are essential to support and maintain other ES (*e.g.* soil formation, or nutrient cycling). Provisioning services comprehend goods resulting from targeted ecosystems, such as food and water. Regulating services are those expressing the benefits resulting in the regulation of certain processes such as climate regulation or pest control. Finally, cultural services include the nonmaterial benefits attained which reflect the aesthetic and/or recreational value of an ecosystem (MEA, 2005). As referred before, assignment of indicators to each ES categories followed the description and usage of each one according to the original source.

Statistical analysis of the information gathered during Step 1 aimed to achieve deeper insights regarding: i) the distribution of case-studies; ii) the dominant scales tackled across case-studies; iii) the variance regarding types of extensive forestry practices; iii) the prevalence of spatially-explicit indicators; and, iv) the number of times each indicator was used to assess forest naturalness and/or habitat quality. Ultimately, such analysis allowed us to identify a core set of spatially-explicit indicators, often used to assess forest naturalness, thereby suitable to map and monitor High Nature Value forests. Eligible indicators which matched the selection criteria were considered for the following step, focusing their usage in case-studies targeting ES mapping and assessment. After Steps 1 and 2, the link between forests with High Nature Value and the potential provision of ES was visualized through network graphs, which allowed exploring the relation between the frequency of use within groups of indicators on forest naturalness, across pre-defined indicators groups and between these groups and ES types. Network diagrams were analysed using Cytoscape software (Shannon *et al*., 2003).

## 2.3. Results

The literature search resulted in 940 abstracts for review. Out of those, 136 papers were identified as potentially relevant. Full paper selection resulted in 90 articles reporting on indicators of forest naturalness and/or habitat quality (Step 1; see Appendix I) and 46 articles on indicators that have been used explicitly in the assessment of ecosystem services (Step 2; see Appendix II).

### 2.3.1. Indicators of forest naturalness

Overall, most of the articles retrieved during the first step addressed naturalness at the stand level (56%), followed by landscape (20%), regional (4%) and national (5%) scales of analysis. A total of 15% of studies did not present any information regarding the scale of analysis. For management practices, most studies were conducted in areas under extensive management (30%) or being managed sustainably (25%). In 20% of the cases, no management was practiced and from all studies scrutinized, 25 did not report type of management. From the 90 selected studies, only 15 (17%) referred to indicators with a spatially-explicit component. Regarding study location, the majority of the studies were conducted in Italy (n=13). Countries in the Northeast of Europe also contributed with a relevant number of studies (n=24), namely Sweden (n=10), Finland (n=7) and Estonia (n=6).

### 2.3.2. Assessment of naturalness and habitat quality across forest ecosystems under extensive management

The literature search performed in Step 1 resulted in the identification of 38 indicators expressing distinct features of forest naturalness, grouped into 5 pre-defined categories (Figure 3; see Appendix III). Overall, the distribution of indicators within the five categories was as follows: Landscape (n=13), Composition (n=11), Structure (n=10), Management (n=7) and Environmental related (n=6). Specifically, focusing on the frequency that each set of indicators was used throughout the selected studies (*cf*. Figure 3), 33% of them were related to Structure, 23% to Landscape, 20% to Composition, 10% to Management, and 6%, Environmental. Single occurrences (*i.e.*, identified indicators being used in the literature only once and named as Others) accounted for 8% of indicators. Within Landscape indicators, natural disturbance (n=34) and naturalness (n=25) were among the most commonly mentioned indicators. Tree species composition (n=28) and species diversity (n=14) were the indicators most often used to express composition. Tree size (n=44) and stand structure (n=34) were the most common indicators implemented to express the structure (of the forest). As for Management, deadwood (n=27) was found to be the most frequent indicator, followed by forest age structure (n=16). Finally, regarding Environmental indicators, slope and elevation were found to be the most frequently used (n=5).

Some indicators were found to be used to express more than one dimension of forest naturalness (Figure 3). Overall, from the 38 targeted indicators, 9 were assigned to more than one category, 7 to two categories, and 1 to three categories of indicators (Deadwood; Figure 3). Structure included the highest number of common indicators (n=6), followed by Composition (n=5), Management (n=5), Landscape (n=3) and Environmental (n=1). Specifically, deadwood (n=64) was found to be used as indicator to express three dimensions of forest ecosystems (composition, structure and management). Besides deadwood, tree size (n=44) and forest age structure (n=37) were the most frequent indicators among the surveyed studies, informing on structure and structure and management, respectively.

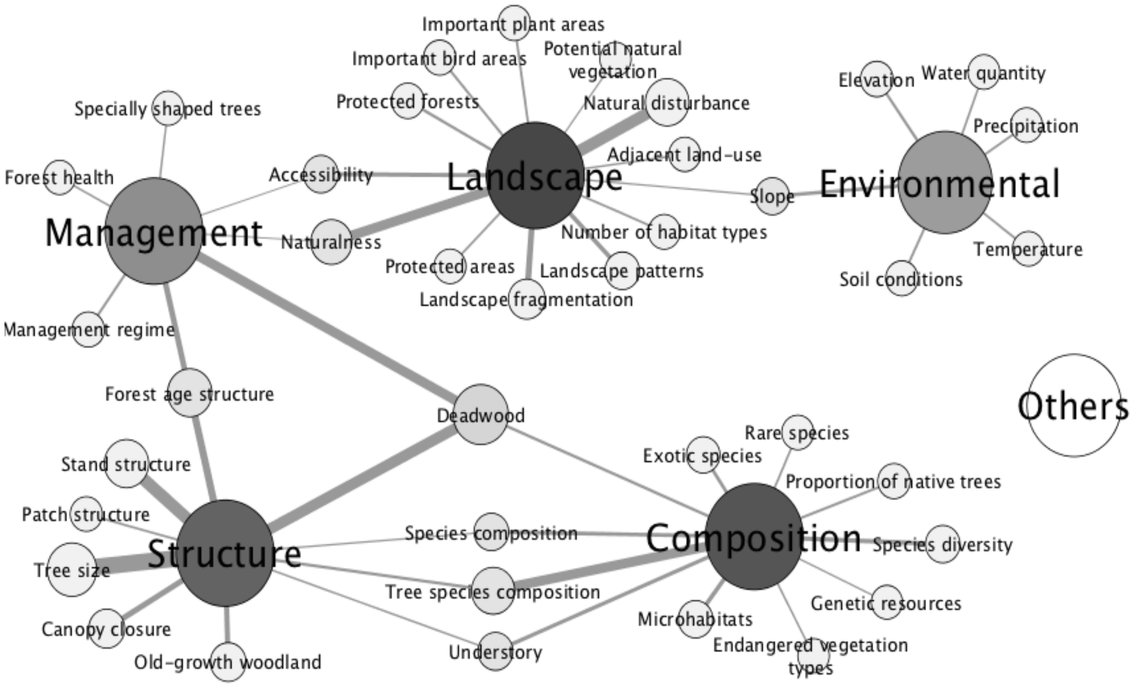


**Figure 3.** Network diagram representing indicators grouped by category. Node size, color range (lighter to darker) and scale range reflect the increasing number of times each indicator was used. Edge depicts the number of times these indicators were used in relation to each category.

### 2.3.3. Linking the nature value of traditionally managed forests and the potential provision of ecosystem services

From the 38 indicators identified within Step 1, 21 (55%) were found to be used in research tackling the assessment and/or quantification of ES in forest ecosystems (Step 2; Figure 4; see Appendix IV).

Out of those 21, 14 were used in research focusing regulating services, whereas 14 targeted cultural services, 8 provisioning services and 3 supporting services. Regarding the frequency of indicators used in relation to service types, regulating services were the most frequently used (52%), followed by cultural (32%), provisioning (11%) and supporting services (5%).

Overall, when analysing the frequency of individual indicators, tree size (ca. 15%), canopy closure (ca. 10%) and accessibility (ca. 9%) were found to be the most used in the assessment of ecosystem services in forests. Out of these, accessibility was the only indicator used in the estimation of just one ecosystem service type, more specifically, cultural services. Tree size and canopy closure were referred as being used to estimate the potential of provision, regulation and cultural services.

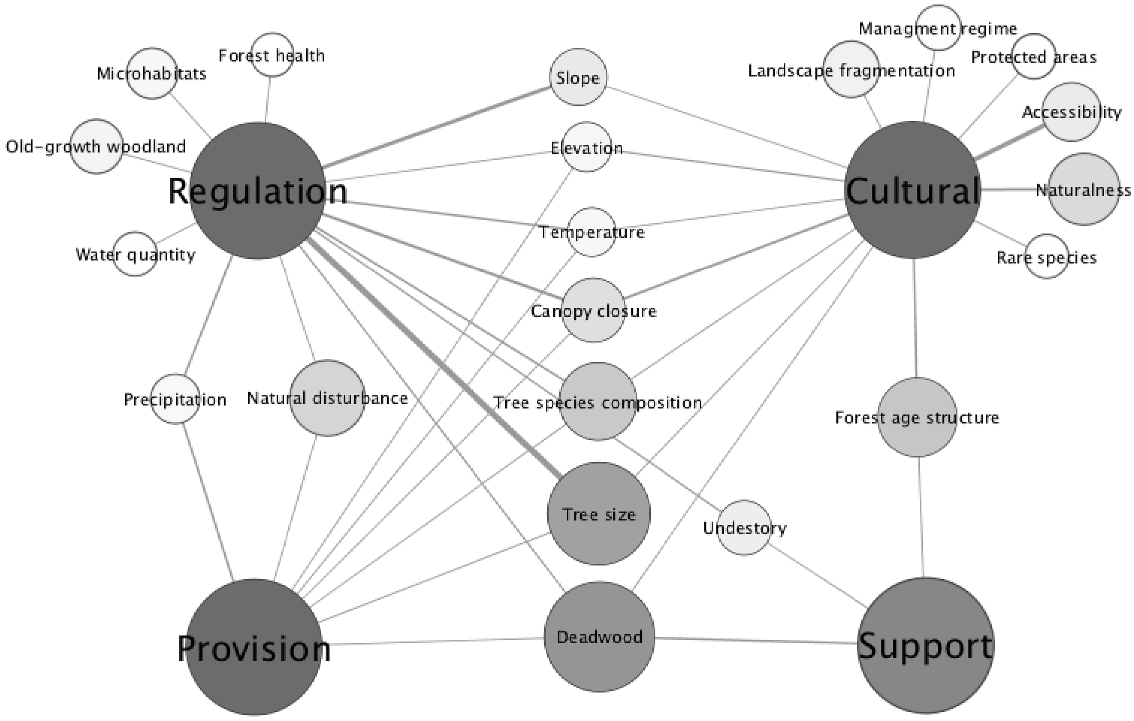


**Figure 4.** Network diagram representing naturalness indicators used in ecosystem service assessment grouped by type. Node size, color range (lighter to darker) and scale range reflect an increasing number of times each indicator was used. Line depicts the number of times these indicators were used in relation to each category.

Over half of the indicators (n=11) were used in the assessment and/or quantification of more than one type of ES (Figure 4). All indicators used in the assessment of provision and support services were also used in the assessment of other types of services. Out of the 14 indicators used in the assessment of regulation services, over half (n=10) were used in the assessment of other ecosystem services. Over half of indicators used in relation to cultural services (n=8) were also used in the assessment of multiple service types.

Out of the 12 indicators assigned to multiple groups, 5 were used in the assessment of two ES types, and 6 to three ES types (Figure 4). Deadwood was the only indicator used in the assessment and/or quantification of all four service types.

Most of the indicators used in the assessment of the four ES types were Structure-related indicators (Figure 5). Provisioning, regulating and cultural services are assessed using several indicators; supporting services are mainly assessed through management, structure and composition-related indicators (Figure 5).

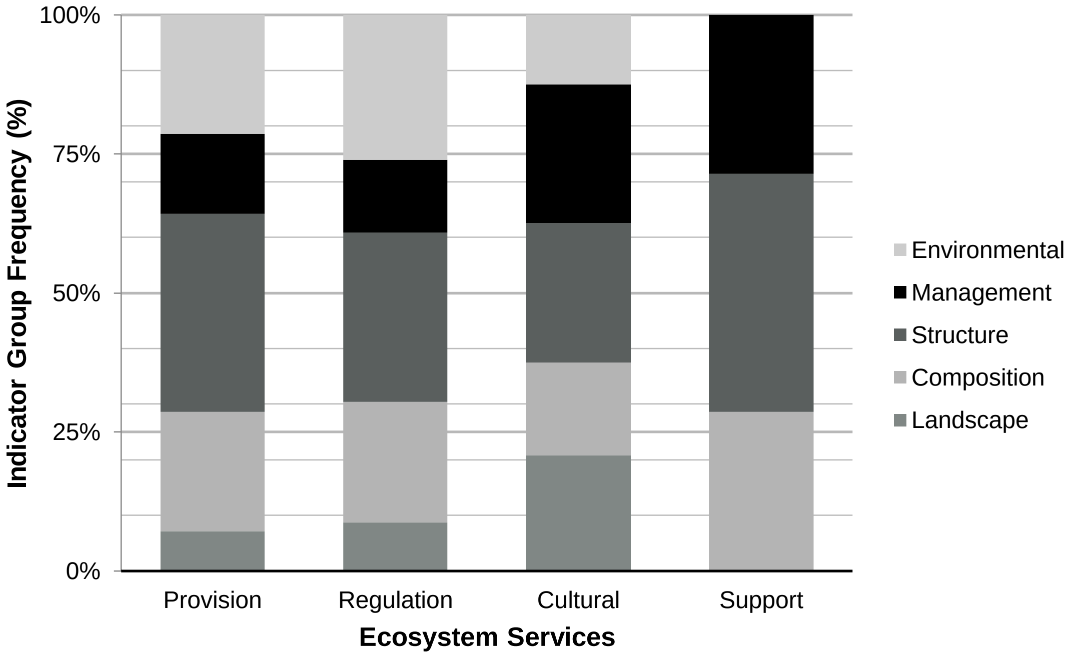


**Figure 5.** Relative distribution (%) of indicators *per* category and *per* ecosystem service type.

Overall, deadwood (n=77), tree size (n=64) and forest age structure (n=40) were the most frequent indicators. All of them are structure-related indicators. Deadwood (n=7), dominant trees (n=6) and tree species composition (n=5) are the indicators used in the highest number of groups.

## 2.4. Linking the nature value of traditionally managed forests and the potential provision of ecosystem services

Traditional landscapes are amongst the most important areas in Europe for conservation as they are characterized by a high nature value, whilst providing several fundamental goods and services. But these remote often extensively managed landscapes, are often areas with low productivity, which makes them prone to abandonment, threatening both their social and ecological capital. Maintaining and improving HNV areas has been encouraged by EU environmental policies, such as the agro-environment schemes (Regulation (EU) No 1305/2013). Nevertheless, the absence of a common methodological framework and suitable indicators that can be applied by Member State (MS) and across the EU to assess the extent and condition of such areas compromise their maintenance in the future. Thus, improving overall knowledge regarding the nature value of rural landscapes, and the potential relation between HNV and the provisioning of multiple ecosystem services, is a pressing need to assure environmental sustainability.

### 2.4.1. Assessment of naturalness and habitat quality across forest ecosystems under extensive management

Overall, whilst most of the targeted case studies focused on extensively managed forests (See section 2.3 for detailed results), only few referred to unmanaged forests. This trend is in line with previous research reporting only 3% of European forests as being classified as natural (Forest Europe, 2015, Thies *et al*., 2011). As expected, most studies were found to be originated in North European countries, such as Sweden, Estonia, Finland and Lithuania, as these correspond to countries where extensively managed and/or natural forests are more abundant (Forest Europe, 2015). Also Italy was found to be a relevant contributor to research targeting this type of forests which may be related to the fact that Italy is the European country exhibiting the highest percentage of protected forest area (Forest Europe, 2015).

Stand and landscape were found to be the most frequent scales of research (*cf.* Appendix I). Overall, these results highlight the fact that existing metrics and indicators are mostly implemented at stand and landscape levels, even though broader scales of reporting have been required (*e.g.* national scale). Research performed at higher spatial resolutions is essential to achieve a better understanding on the patterns of nature value across EU rural landscapes, and converges with bottom-up approaches to report at broader scales (*e.g.* see Lomba *et al*., 2014).

Ecological indicators have been widely used in the assessment of forest naturalness and/or habitat quality (Liira and Sepp, 2009). However, our study highlighted that there is a lack of research targeting the spatially-explicit assessment of High Nature Value forests, expressed as a very low number studies on this topic. Broadening our target to forests under extensive management, which have been correlated to High Nature Value (See IEEP, 2007), analysis pinpointed the lack of consistency of indicators used to express forest naturalness, and the lack of coherence across terminology. These facts were found to be expressed by a high number of distinct indicators initially retrieved from the references analysed (n=124 indicators), reduced (to 38) after a thorough analysis and grouping of indicators conveying the same information (initially with distinct designation).

Traditionally, good ecological indicators are those that represent essential information regarding the structural, compositional and functional elements of the ecosystem (Dale *et al*., 2001). Besides, as assessment and monitoring programs often depend on the use of a small number of indicators, it is important that these indicators meet a series of other criteria such as measurability, specificity, reliability, universality, cost-effectiveness, international compatibility, and replicability (Niemeijer and de Groot, 2008).

High variation regarding the number of indicators used within each study was observed. In fact, whilst some case-studies consisted of a broad analysis of multiple indicators to express several dimensions of forest naturalness, others presented conservative approaches were few specific indicators and their correlation with forest naturalness and/or habitat quality was scrutinized. Literature analysis highlighted structure and landscape indicators as the most commonly used. The use of these indicators in detriment of others is likely influenced by their characteristics, such as cost-effectiveness and measurability, which results in an easier use when compared to composition and management based indicators (Gao *et al*., 2014, Gao *et al*., 2015). Moreover, the application of these indicators at different scales throughout Europe suggests high universality and replicability (Niemeijer and de Groot, 2008).

Regarding management indicators, landscape metrics and patch structure and composition indicators (*e.g.* accessibility) can be used as proxies of management regimes and provide vital information regarding hemeroby in forest areas.

Environmental indicators are the least used within consulted references. However, the abiotic component of the landscape where the forest is included can provide assertive information on the existence of certain natural limitations (*e.g.* existence of steep slopes) that can be used as proxies to assess the extension of management and human influence in that area. Moreover, as HNV forests tend to be situated in areas with natural constrains, these indicators, particularly slope, can be useful in the mapping of these forests.

Some of the indicators detected in our research could potentially provide information on more than one forest dimension as the same indicator can be used within more than one indicator groups (*e.g.* dominant trees, slope). These indicators are particularly useful as they provide more information than those that can only inform on one particular aspect of forests. The use of these indicators is therefore advantageous as they allow the simplification of the methodology without compromising the quality of the information obtained making them more cost-effective (Niemeijer and de Groot, 2008). Our results suggest that some indicators, due to their characteristics, are more suitable than others to be used for the assessment of HNV forests. Even though some of the analysed indicators (*e.g.* deadwood) present higher reliability, as they present better track records, the lack of good available data at European scale limits their use. In this situation, rough proxies can be used and later replaced by other, more reliable indicators, when sufficient data is available (Hengeveld *et al*., 2012). Therefore, it is important, when proposing indicators to be used on a common methodological framework, to consider simultaneously all relevant criteria (*e.g.* measurability, replicability).

### 2.4.2. Linking the nature value of traditionally managed forests and the potential provision of ecosystem services

Understanding the links between nature value and the provisioning of ecosystem services in rural landscapes has been highlighted as essential to assure the future socio-ecological sustainability of such forests (Hagyo *et al*., 2015). Overall, this research focused on the identification of indicators that could assess forest naturalness and/or habitat quality in forests under extensive management, whilst enabling to ascertain their potential for providing multiple ES. Our analysis resulted in the identification of 21 indicators (*cf.* Figure 4) which have been used in research targeting the assessment of forest naturalness and/or quality and at the same time the provision of goods and services. The majority of these indicators can be used in the assessment of more than one of the four types of ecosystem services considered. For example, deadwood can be used in the assessment of all ecosystem service types (Figure 4). Considering the need for cost-effective methods to assess ecosystem service provision, the existence of several indicators that can be used in the evaluation of multiple ecosystem functions and services is beneficial (Grêt-Regamey *et al*., 2008).

Results have shown that a higher number of naturalness and/or forest quality indicators has been used in the assessment of regulation and cultural services. This would be expected when considering that $HNV_{forests}$, due to their characteristics, are less productive than similar areas that are more intensively managed and therefore provisioning services should be less relevant in these areas when compared to regulating and cultural services (Hagyo *et al*., 2015).

In terms of regulating services, most of the indicators used are linked to the quantification of carbon sequestration in forest areas and its effect on climate regulation. The current relevance of this topic is probably one of the main reasons for this. Regarding cultural services, the strong connection between public preferences and the provision of this type of services facilitates the finding of useful indicators and therefore the assessment of these services. These findings suggest that $HNV_{forests}$, due to the inherent characteristics that result from the type of management practiced in these areas, are preferred for their aesthetic value and can be valuable areas for activities like ecotourism.

Once again, for the same reasons mentioned in the previous section, authors tend to prefer the use of structure indicators in the quantification of the different types of services provided (*cf.* Figure 5). The predominant use of structure indicators is, as previously mentioned, related to the characteristics of these indicators including the existence of spatial and temporal data. Besides that, these indicators provide vital information regarding forest functions and consequently service provision. Cultural services represent an exception as they are mainly evaluated through the use of management and landscape indicators, as landscape metrics and management regime are the forest characteristics that seem to influence personal preferences for cultural services the most.

## 2.5. Conclusions

The absence of a replicable methodological framework paired with the absence of spatial and temporal data for the application of indicators resulted in the delay of HNV forests reporting. Even though there are several global databases with available data referent to forest ecosystems (*e.g.* GEO BON, GEOSS), the data provided is coarse and therefore can only be used at larger scales. The fact that most of the consulted studies were realized in smaller stand scales is also problematic as the reporting is done at regional and/or national scale (IEEP, 2007) and the extrapolation to larger scales is difficult and often misleading (Gao *et al*., 2015).

In order to improve the assessment and mapping of HNV forests, the development of a methodological framework that can be adapted to different areas within the European Union as well as to different forest types is fundamental. To do so, it is necessary to select a small number of indicators that are commonly used and are proven to be related with forest natural features and can provide information on the different forest dimensions (*e.g.* management, landscape, composition and structure). When selecting these indicators, it is important to take into account whether or not there is spatial and temporal data available with good coverage within Europe and, in case the necessary information is unavailable, if any proxies can be used to obtain the needed information regarding these indicators. It is also important to consider indicator reliability measured as the frequency of use.

Taking this into account, our results have shown naturalness indicators that fulfil these requirements and therefore can be used in the assessment of $HNV_{forests}$. Considering temporal and spatial data availability, indicators like landscape patterns and patch structure, that can be calculated based on land cover data available at Europe-wide scale, are some of the most useful and can provide fundamental information regarding both landscape and forest structure. Regarding forest composition, using land cover or forest inventory data, whenever available, tree species composition can also be assessed and used as an $HNV_{forest}$ indicator. Lastly, as forest management is closely linked to forest accessibility, the use of indicators like slope and distance to urban areas, that can be calculated respectively through digital elevation models and land cover maps, can be helpful in the mapping of these areas.

Our results also suggest a connection between natural value and service provision, however it is necessary to invest in research in this area in order to demonstrate the multifunctional role of these forests. Therefore, the development of a practical methodology that allows the mapping of $HNV_{forests}$ and compare the service provision in these areas when compared to non-$HNV_{forests}$ is essential.

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# Chapter III. Assessing the High Nature Value forests: the case study of the Rio Vez Watershed

**Abstract**

The High Nature Value forest ($HNV_{forest}$) concept has been highlighted in the EU environmental and rural policies due to the inherent value of these ecosystems regarding, not only high biodiversity levels, but also to the wider provision of ecosystem services. The assessment of $HNV_{forest}$ areas, implies the existence of a framework, able to accommodate different indicators informing on forest structure and composition, but also on management practices. Yet, the lack of a common methodological approach has hinder the ability of the European Union to tackle such challenge.

A previously described methodological approach to assess HNV farmlands was adapted and implemented in a case study rural area in northern Portugal, the Rio Vez watershed. Indicators used were selected according to their reliability and the existence of spatial and temporal data with good resolution. The coincidence of $HNV_{forests}$ with Natura 2000 and other protection status in the targeted area was then assessed to scrutinize the potential of $HNV_{forests}$ to contribute to the maintenance of biodiversity.

The application of the framework allowed the identification of three distinct clusters of civil parishes within Rio Vez watershed. These clusters differed in terms of patch size, edge regularity, accessibility and consequently forest naturalness. Analysis of the coincidence of $HNV_{forests}$ with Natura 2000 and other protection instruments showed that the majority of $HNV_{forests}$ are outside protected areas. Such results suggest that such forests may contribute for biodiversity conservation and the provision of ecosystem services in the EU countryside, thus contributing to meet societal demands on environmental sustainability and EU's ambitious goals. Yet, it is essential to further understand the drivers underlying the nature value of such forests. While this case-study contributed to advance the assessment of HNV $HNV_{forests}$ in Europe, more research is needed, namely by testing other indicators (with higher thematic and spatial resolutions) and by targeting other different socio-ecological contexts. When coupled with different land-use scenarios, this methodological approach may provide key information regarding the impact of political decisions on biodiversity and ecosystem service provision in rural Europe.

**Keywords**

High Nature Value Forests, Rural Development Policies, Ecological Indicators, Forest naturalness

## 3.1. Introduction

Worldwide, forests have been acknowledged for their fundamental role as providers of diverse ecosystem services (ES) (FAO, 2006, Shvidenko *et al*., 2005). Whilst forest ecosystems have been described as essential habitats for several wildlife species, including species of conservation concern (*e.g. Accipiter gentilis*; *Crotalus horridus*; *Callophrys henrici*; *Lasiurus borealis*), such role closely relates to the maintenance of close-to-natural, vital, healthy, resilient, multifunctional forests (EEA, 2010). However, the joint effect of intensive forest management and environmental change (*e.g.* climate and land-use change) have been highlighted as major drivers of natural and semi-natural forest loss and degradation (SCBD, 2009). Forest naturalness, in which the provision of several ecosystem services and biodiversity maintenance underlies, has been described as the similarity of the current state of an ecosystem to its natural state (EEA, 2014, Winter, 2012). Such relationship has been widely acknowledged within the European Union (EU) policies, particularly those focusing biodiversity maintenance and preservation under environmental change (EEA, 2014). Such policies include Rural Development Programmes (RDP's) that, among other goals, aim to restore, preserve and enhance ecosystems related to agriculture and forestry, focusing on areas facing natural constrains and High Nature Value areas.

The High Nature Value (HNV) concept, devised in the 90's, targeted areas where the maintenance of extensive management practices and biodiversity levels were high and/or species and habitats of conservation concern were present (Baldock *et al*., 1993). Even though this concept was initially focused on the causality between extensive farming practices and natural value, the HNV concept has since been broaden and implemented on rural landscapes to include forest areas due to the inherent value of these ecosystems regarding, not only high biodiversity levels, but also the provision of several ecosystem services (EEA, 2014, IEEP, 2007). The relevance of HNV farmlands and forests maintenance was first acknowledged within Rural Development Policies and integrated in the second pillar of the Common Agricultural Policy (CAP; Regulation (EU) No 1305/2013). These policies aimed to meet economic, environmental and social challenges in European rural areas through the improvement of the environment and countryside through, namely, the restoration, preservation and enhancement of biodiversity in HNV areas (Council Decision 2006/144/EC).

The nature value of forests was further included. Initially it was part of the European Union (EU) Biodiversity Action Plan (COM (2006) 216), which aimed to contribute to halt biodiversity loss on such ecosystems until 2010, and later in the EU biodiversity strategy to 2020, that aims to halt biodiversity loss in Europe by 2020, by contributing for the 'conservation status of species and habitats that depend on or are affected by forestry and in the provision of related ecosystem services' (COM (2011) 244).

Overall, High Nature Value forests ($HNV_{forests}$) are defined as natural and semi-natural forests where the maintenance of extensive forestry practices support a high diversity of native species and habitats, and/or the presence of species of conservation concern (IEEP, 2007). As so, whilst natural and some specific semi-natural forests under certain management regimes are potentially HNV, several semi-natural and plantation forests have been classified as non-HNV (IEEP, 2007). Overall, the discrimination between HNV and non-HNV forests builds on the type of management practices and whether such practices mimic (or not) natural processes, including traditional practices often linked to the maintenance and enhancement of high biodiversity levels (IEEP, 2007). The high diversity of native species and habitats and/or the presence of species that are particularly valuable conservation-wise has supported the inclusion of these $HNV_{forests}$ in protected areas (Pignatti *et al*., 2012). However, $HNV_{forests}$ can also be found outside these units, particularly in poorer rural areas where intensification is difficult, making their protection important in the context of the EU ambitious environmental goals (EENRD, 2009).

Assessing and monitoring the nature value of forests imply that Member States (MS) need to identify and implement indicators, at national or regional scales, which will enable to target such areas in space and time (IEEP, 2007). Nevertheless, the lack of a systematic framework allowing the identification of $HNV_{forests}$ through EU has led to a delay in the assessment of such areas when compared to the identification of HNV farmlands (Scottish Government, 2011). The lack of reliable data sets with sufficient spatial and temporal resolution that allow a precise assessment of the extent of these areas, much like in the assessment of HNV farmlands, is also a significant justification to this delay (Lomba *et al*., 2015).

Here, we aimed to contribute to the development of a multi-criteria methodological framework, that can be used for the assessment of the nature value of forests across the EU rural landscapes. A range of indicators expressing key characteristics of HNV forests (landscape, management practices and biodiversity values) were used and the methodological framework proposed by Lomba *et al.* (2015) targeting the assessment of High Nature Value farmlands was adapted. Overall, a combination of different indicator sets expressing the most important dimensions of $HNV_{forests}$, including data expressing landscape elements, forest management and patch structure and composition, was used and implemented recurring to a Geographic Information System (GIS) in the Rio Vez watershed, located in North-western Portugal, with the objective of assessing $HNV_{forests}$

extent in this sample area. Areas with potential to be classified as HNV forests were spatially assessed, and latter overlaid with areas under legal protection to disclose their potential to support high levels of biodiversity. Finally, results were discussed in the context of the assessment of the nature value of forests in the EU, and the potential role of such forests to the EU common environmental goals.

## 3.2. Methods

### 3.2.1. Study Area

The study area encompassed 53 civil parishes included (entirely or partially; when partially, the entire area of the civil parish was included in our study area) in the Rio Vez watershed, located in the Northwest of Portugal (Figure 6). Overall, the targeted area occupies ca. 550 km$^2$, distributed throughout five municipalities: Arcos de Valdevez (ca. 73 % of the study area; 41 parishes), Melgaço (ca. 7%; 2 parishes), Monção (ca. 14%; 5 parishes), Paredes de Coura (ca. 5%; 4 parishes) and Ponte de Lima (ca. 1%; 1 parish). The study area is characterized by a complex topography, with altitude ranging between 11 and 1401 meters, and slope between 0 and 54%. Average annual precipitation and average annual temperature values are 1500 mm/year and 13.8 ºC, respectively (Instituto Português do Mar e da Atmosfera - IPMA). Located partially in the Peneda-Gerês National Park (ca. 25,1% of the study area, in the south-eastern part; *cf*. Figure 6), the targeted area also includes the Site of Community Importance ´Peneda/Gerês' (PTCON0001) and the Special Protection Area ´Serra do Gerês´ (PTZPE0002) of the EU Natura 2000 network. Further, the western part of the study area includes the 'Corno do Bico' Protected Landscape (ca. 2,9% of the study area) also classified as SCI (PTCON0040). Lastly, our study area also includes the Lima river (ca. 2% of the study area) classified as SCI (PTCON0020) (Figure 6).

Within the study area, regosols and leptosols are predominant in highlands, dominated by open areas of bare rock and heath, scrubland (broom) and transitional forest areas, whereas anthrosols, fluviosols and technosols are predominant in lowlands, dominated by agricultural and forest areas. Urban areas and roads are mainly found around main water courses (Figure 6). Farmlands are mostly concentrated near river banks where humidity and soil types appear to be more suitable for agricultural practices (Figure 6). Forests in the area are mainly dominated by *Pinus* and *Quercus* species, and represent ca. 39% of the land-use in the study area. Broadleaf dominated forests are widespread throughout this area whereas coniferous dominated forests are absent in the southeastern part of the study area and forests dominated by bluegum (*Eucaliptus globulus*) and other exotic species are located almost exclusively in the western part.

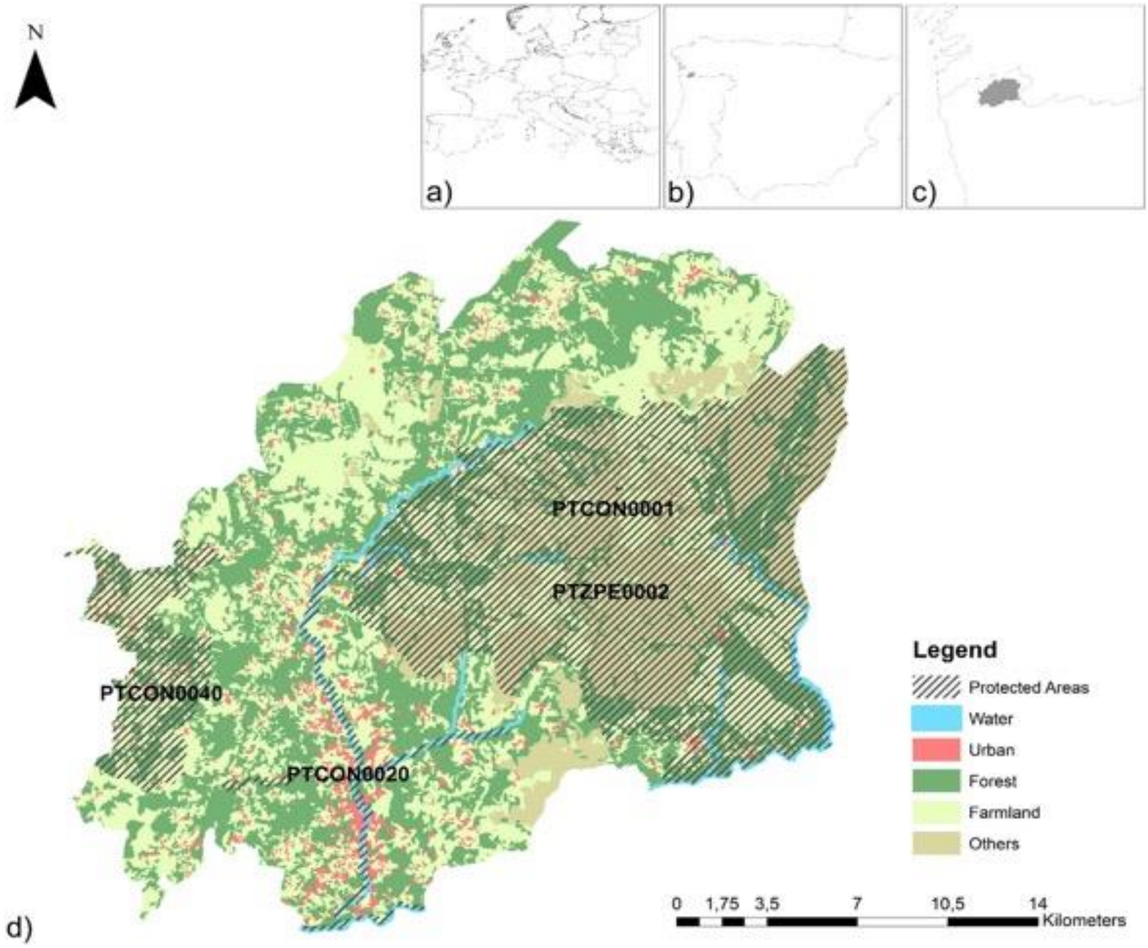


**Figure 6.** Geographic location of the study area, the civil parishes included in the Vez's River watershed in the national (c), Iberian (b), and European contexts (a); in (d) the main land-use classes occurring in the study area are shown. Protected areas included in the study area are also presented and include Sites of Community Importance ´Peneda/Gerês' (PTCON0001), 'Corno do Bico' Protected Landscape (PTCON0040) and Lima river (PTCON0020) as well as Special Protection Area ´Serra do Gerês´ (PTZPE0002).

### 3.2.2. Spatially-explicit assessment of High Nature Value forests

Whilst highlighted as essential for the conservation of EU natural heritage, assessing the extent of forests of High Nature Value is still a challenge to tackle. Overall, such challenge builds on the lack of a common framework and the scarcity of data, with adequate spatial and temporal resolution (See Chapter II). Whilst efforts have been invested in the development of pan-European (EEA, 2014) and regional assessments (Petrontino and Fucilli, 2013), there is a pressing need for identifying and testing spatially-explicit indicators that can support the identification of the extent and condition of such forests. Built on results from previous research (for details see Chapter II), an existing methodological approach used in the assessment of HNV farmland was adapted for $HNV_{forests}$ assessment. This framework considers several dimensions of nature value to accurately assess the extent of $HNV_{forests}$, captured through three sets of indicators reflecting: 1) Landscape; 2) Management; and, 3) Patch Structure and Composition (Table 7). The use of the different sets allowed the inclusion of information regarding different High Nature Value forest ($HNV_{forest}$) dimensions, namely landscape diversity, management intensity, naturalness of forest composition and structure and the occurrence of species of conservation value. Indicators used within the implementation of such approach were selected according to the following criteria: 1) rationale or how well indicators expressed information regarding the considered forest dimensions; 2) existence of available spatial data; and, 3) frequency of use of the indicators in previous studies (See Chapter II).

First the dominance of urban, farmland and forest cover (expressed as percentage) per civil parish was determined based on land cover data available for the study area (Table 7; IGEO, 2007). Dominance of land-use classes was used to exclude parishes dominated by urban areas, and to further discriminate between civil parishes dominated either by farmlands or forests. $HNV_{forest}$ categories included forest classes dominated by cork oak (*Quercus suber*), evergreen oak (*Quercus ilex*), sweet chestnut (*Castanea sativa*), other oak species, other broadleaf species, stone pine (*Pinus pinea*) and other coniferous as proposed by the Portuguese Ministry of Agriculture and Sea (Ministério da Agricultura e do Mar, 2015). Categories where such species were co-dominant were also included. As previous studies highlighted, the nature value of both closed and open forests containing the aforementioned species were considered as potential HNV forests (Scottish Government, 2011). Lastly, land-cover areas classified as woody formations, areas occupied by forest species that, due to the conditions they live in, can't grow more than 5m in height, were also selected as these areas may evolve towards forest structures with HNV potential (Pignatti *et al*., 2012).

After ascertaining classes to be considered as $HNV_{forests}$, a minimum-maximum approach as described by Andersen *et al*. (2003) was implemented to discriminate the potential of such classes to exhibit HNV. Overall, $HNV_{forest}$ minimum expressed land-cover classes with higher potential to constitute $HNV_{forests}$ and included land-cover types that had primarily HNV value (for detailed information see Appendix V). Conversely, $HNV_{forest}$ maximum included categories with lower nature value, and included other forest related land-cover classes. $HNV_{forest}$ Minimum categories targeted classes expressing natural and/or semi-natural forest composition such as those dominated or co-dominated by cork oak, evergreen oak and other oak species whereas $HNV_{forest}$ Maximum included forests dominated or co-dominated by sweet chestnut and other broadleaf species as well as native coniferous species. A total of 20 forest categories were accounted as

$HNV_{forests}$ in our study area. Out of these, 6 were $HNV_{forest}$ Min categories and the remaining 14 were $HNV_{forest}$ Max categories.

All spatially-explicit analyses were conducted using the Spatial Statistics Toolbox for ArcGIS 10.3.1 Desktop (ESRI, 1999-2015). Regarding management indicators (*cf.* Table 7), mean slope values (Mean S) for each parish were derived from a Digital Elevation Model (DEM; SRTM 30m; USGS, 2010; http://srtm.usgs.gov/) using the Spatial Analyst toolbox, available in ArcGIS 10.3.1 (ESRI, 1999-2015). Distance between forest and urban patches, expressed as mean distance (Mean DIST; *cf.* Table 7), for each parish was calculated using the NEAR tool in ArcGIS 10.3.1 Desktop (ESRI, 1999-2015). Finally, the ArcGIS extension, Patch Analyst (Rempel *et al*., 2012) was used to determine indicators expressing landscape patterns as well as patch structure indicators. Spatial Autocorrelation analysis (Global Moran's I; ESRI, 1999-2015) was first applied to all targeted spatially-explicit indicators to evaluate patterns (clustered, dispersed or random). Subsequently, only indicators found to exhibit clustered patterns, expressed as statistically-significant positive Moran's I index values, were considered. Cluster analysis for targeted indicators was performed using the Mapping Clusters toolset (ESRI, 1999-2015). To ensure that all groups include members that have natural neighbour's, the Grouping Analysis tool was implemented with 'Contiguity edges only' as spatial constraints parameters. Outcomes included overall and within groups statistics, the discrimination ability of each indicator considered for analysis (expressed as higher $R^2$ values), and an evaluation of the optimal number of groups. Optimal number of groups are expressed as higher values for the pseudo F-statistic, and reflect a trade-off between the numbers of groups and indicators used in the analysis (*cf.* ESRI, 1999-2015). Correlations between all indicators were evaluated through the application of the Kendall Tau test, with a maximum value of 0.7 assumed as higher limit for variables inclusion (Lomba *et al*., 2010).

**Table 7.** Sets of indicators used within the spatially-explicit assessment of High Nature Value forests. Selected indicators expressing landscape diversity (Landscape), management intensity (Management), naturalness of forest composition and structure (Patch structure and composition) are described and the rationale underlying their selection highlighted.

| Sets of Indicators | Indicators | Code | Source | Description and rationale | References |
|---|---|---|---|---|---|
| **Landscape** | | | | | |
| Landscape elements | Forest dominance in the landscape | FOR<br>FARM<br>URB | COS (2007) | Areas with higher percentage of forests (FOR) than farmlands (FARM) and urbanized areas (URB). As urban areas we considered all artificial surfaces (Category 1, COS 2007). As farmlands all agricultural areas were considered, including areas occupied by heathlands, herbaceous and sclerophyllous vegetation located in areas suitable for agriculture. As forests all open and closed broadleaf, conifer and mixed forest categories as well as other woody formations, rare cuts and new plantations were included. | Lomba *et al*., 2015 |
| | Mean Patch size | MPS | COS (2007) | Represents the size of the forest fragments in the landscape. Informs on the area of functional habitat for different forest species (Pătru-Stupariu *et al*., 2013). Heterogeneity in patch size influences biodiversity (Duncker *et al*., 2012). Smaller patches are perceived as less natural (Ode *et al*., 2009). | Brunet *et al*., 2010, Kovac *et al*., 2016, Langanke *et al*., 2005, Lindenmayer *et al*., 2000, Renetzeder *et al*., 2010, Tierney *et al*., 2009 |
| | Edge density | ED | COS (2007) | Standardizes edge to a per unit area basis facilitating the comparison amongst landscapes of varying size. A more varied edge is normally a more natural one (Bell, 1999). | Langanke *et al*., 2005, Petrontino and Fucilli, 2013, Renetzeder *et al*., 2010 |
| | Shannon Eveness Index | SEI | COS (2007) | Measures countryside diversity according to the number of different patch types and their size distribution amongst the landscape (Bielecka and Ciołkosz, 2004). Landscape diversity generally implies higher biodiversity (Giordano and Boccone, 2010, Lomba *et al*., 2015). | Langanke *et al*., 2005, Lindenmayer *et al*., 2000, Petrontino and Fucilli, 2013 |
| **Management** | | | | | |
| Accessibility | Slope | Mean S | DEM | Represents the change in elevation within a certain area. Terrain slope affects accessibility and consequently hinders management interventions (EEA, 2014). | Angelstam *et al*., 2004, BirdLife International, 2009, EEA, 2014, Maren *et al*., 2013, Veen *et al*., 2010, Yermokhin *et al*., 2007 |

| | | | | | |
|---|---|---|---|---|---|
| | Distance to the nearest urban area | Mean DIST | COS (2007) | Remote areas are less likely to get disturbed by anthropogenic activities (Yaroshenko *et al*., 2001). | Carrasco *et al*., 2014, Hepcan and Coskun, 2004 |
| **Patch Structure and Composition** | | | | | |
| Tree species composition | Dominant trees | $HNV_{forest}$Min/Max | COS (2007) | The dominance of certain tree species reflects site naturalness (von Oheimb *et al*., 2005). Measured as $HNV_{forest}$ Min and $HNV_{forest}$ Max. $HNV_{forest}$ Min represents forest areas within our study area that are more likely to be $HNV_{forests}$ whilst $HNV_{forest}$ Max represents forests that have moderate potential to be $HNV_{forests}$. | Angelstam and Andersson, 2001, Burrascano *et al*., 2013, Hao *et al*., 2007, Leskinen *et al*., 2003, Lombardi *et al*., 2015, Palo *et al*., 2011, Uutera *et al.*, 1996 |
| Patch structure | Mean shape index | MSI_F | COS (2007) | Compares the amount edge of a class or landscape to the amount present on a patch of equivalent size but simpler shape measuring aggregation or clumpiness. Provides information regarding the extension of anthropogenic reshaping in the landscape (O'Neill *et al*., 1988). In this case, the MSI of forest classes was used as an indicator of forest hemeroby. | Langanke *et al*., 2005, Noss, 1999, Petrontino and Fucilli, 2013, Renetzeder *et al*., 2010 |

## 3.3. Results

Analysis targeting dominance across farmland (FARM) and forest (FOR) areas was performed. Overall, results depicted the dominance of urban cover (URB; ca. 60,48%) in the civil parish of Arcos de Valdevez, São Salvador, which was excluded from further analysis. Results highlighted the co-dominance of farmland and forest areas in most of the parishes in the study area (Figure 7). Specifically, the percentage of forest cover ranged between 58,53% in Senharei and 21,65% in Tabaçô, whilst the cover of farmlands was found to vary between 69,12% in Labrujó and 22,44% in Gavieira (*cf.* Figure 7). Further, due to the lack of a clear dominance between farmlands and forests at the landscape level, subsequent analysis were performed in all remaining parishes (n=52).

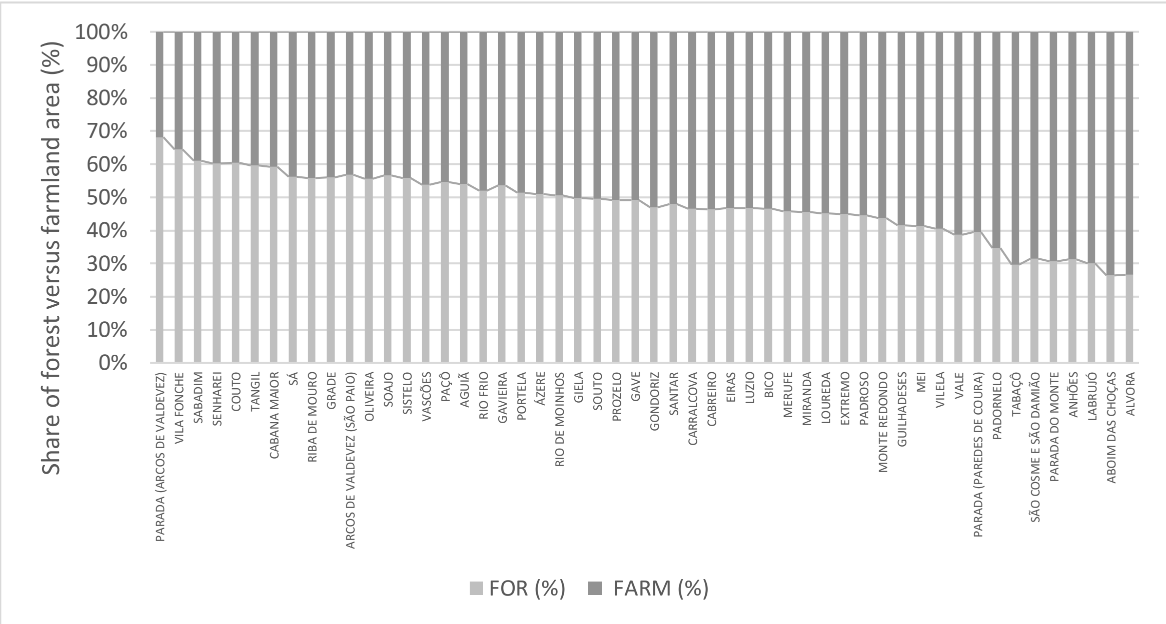


**Figure 7.** Share of forest (FOR) versus farmland (FAR) cover for each of the 52 civil parishes in the study area expressed in percentage cover of these two land-use categories per parish (%).

Grouping analysis, implemented for the 52 targeted parishes, resulted in the discrimination of 3 distinct groups, which are presented in Figure 8. Parishes included in group 1 (n=10), situated in the eastern area of our study area, presented higher mean values for 6 of the 7 used indicators, namely landscape indicators (MPS, ED), management indicators (Mean S, Mean DIST) and patch structure and composition indicators (MSI_F, $HNV_{forest}$Min/Max), with SEI values being the only exception to this pattern (Table 8). Contrastingly, parishes included in group 2 (n=11), situated in the south-western area of the study location, presented lower mean values for the same 6 out of 7 proposed indicators. The third group (n=31), located in the western part of the study area, presented intermediate values for these 6 indicators. SEI values were higher in the second and lower in the first group being intermediate in the third.

Values obtained for the selected indicators in group 2 suggest high anthropogenic disturbance in these areas and therefore parishes included in this cluster were classified as non-HNV areas.


**Figure 8.** Clusters resulting from a grouping analysis build on the three sets of indicators considered, Landscape, Management and Patch Structure and Composition using a total of seven indicators including mean patch size, edge density, Shannon eveness index, mean slope, mean distance between urban and forest patches, mean shape index of forest patches and high nature value minimum and maximum forest categories.

**Table 8.** Results from grouping analysis targeting forests more likely to be High Nature Value forests. Mean, standard deviation (SD), minimum (Min) and maximum (Max) values are presented for each of the seven used indicators: mean patch size (MPS), edge density (ED), Shannon evenness index (SEI), mean slope (Mean S), mean distance between urban and forest patches (Mean DIST), mean shape index of forest patches (MSI_F) and high nature value minimum and maximum forest ($HNV_{forest}$Min/Max). $R^2$ values reflects the discriminating ability of each of the selected indicators. Values are presented for the full extent of our study area as well as for the three parish groups that result from grouping analysis. HNV value refers to the classification of the parish groups HNV potential according to their characteristics. Non-HNV refers to forests in areas whose characteristics don't convey high nature value whilst HNV refers to forests in areas whose characteristics convey high nature value. n, number of municipalities; Ha, hectare; %, percentage; m, meters; n.a., not applicable.

| **Area** | **n** | **Indicator** | **Mean** | **SD** | **Min** | **Max** | **$R^2$** | **HNV value** |
|---|---|---|---|---|---|---|---|---|
| Full Area | | MPS (ha) | 119209.63 | 66671.07 | 33683.33 | 409307.27 | 0.41 | |
| | | ED (n.a.) | $0.03x10^{-2}$ | $0.03x10^{-2}$ | 0.00 | $0.14x10^{-2}$ | 0.72 | |
| | | SEI (n.a.) | 0.74 | 0.08 | 0.56 | 0.91 | 0.15 | |
| | | Mean S(%) | 11.75 | 2.55 | 6.01 | 17.65 | 0.47 | |
| | | Mean DIST (m) | 274.71 | 222.70 | 11.29 | 929.04 | 0.69 | |
| | | MSI_F (n.a.) | 1.96 | 0.20 | 1.47 | 2.50 | 0.37 | |
| | | $HNV_{forest}$Min/Max (%) | 10.49 | 9.29 | 0.00 | 32.63 | 0.20 | |
| Groups | | | | | | | | |
| 1) | 10 | MPS (ha) | 192204.19 | 80378.41 | 115127.76 | 409307.27 | 0.78 | HNV |
| | | ED (n.a.) | $0.08x10^{-2}$ | $0.03x10^{-2}$ | $0.05x10^{-2}$ | $0.14x10^{-2}$ | 0.69 | |
| | | SEI (n.a.) | 0.70 | 0.06 | 0.56 | 0.80 | 0.69 | |
| | | Mean S(%) | 14.65 | 1.85 | 12.51 | 17.65 | 0.44 | |
| | | Mean DIST (m) | 638.65 | 212.94 | 257.54 | 929.04 | 0.73 | |
| | | MSI_F (n.a.) | 2.05 | 0.09 | 1.90 | 2.20 | 0.29 | |
| | | $HNV_{forest}$Min/Max (%) | 14.71 | 6.64 | 5.49 | 28.68 | 0.71 | |
| 2) | 11 | MPS (ha) | 58164.36 | 18835.84 | 33683.33 | 88854.32 | 0.15 | Non-HNV |
| | | ED (n.a.) | $0.01x10^{-2}$ | 0.00 | 0.00 | $0.02x10^{-2}$ | 0.12 | |
| | | SEI (n.a.) | 0.79 | 0.07 | 0.67 | 0.90 | 0.65 | |
| | | Mean S(%) | 9.14 | 1.59 | 6.01 | 12.00 | 0.51 | |
| | | Mean DIST (m) | 89.30 | 72.00 | 11.29 | 215.29 | 0.22 | |
| | | MSI_F (n.a.) | 1.72 | 0.11 | 1.47 | 1.87 | 0.38 | |
| | | $HNV_{forest}$Min/Max (%) | 2.76 | 4.42 | 0.00 | 13.59 | 0.42 | |
| 3) | 31 | MPS (ha) | 117324.23 | 46921.78 | 46873.69 | 217412.90 | 0.45 | HNV |
| | | ED (n.a.) | $0.02x10^{-2}$ | $0.01x10^{-2}$ | $0.01x10^{-2}$ | $0.07x10^{-2}$ | 0.46 | |
| | | SEI (n.a.) | 0.73 | 0.08 | 0.61 | 0.91 | 0.85 | |
| | | Mean S(%) | 11.74 | 1.93 | 7.81 | 15.50 | 0.66 | |
| | | Mean DIST (m) | 223.09 | 95.57 | 19.78 | 412.35 | 0.43 | |

| | | | | | |
|---|---|---|---|---|---|
| MSI_F (n.a.) | 2.01 | 0.19 | 1.67 | 2.50 | 0.81 |
| $HNV_{forest}$Min/Max (%) | 11.87 | 9.73 | 0.00 | 32.63 | 1.00 |

The implementation of the proposed spatially-explicit approach resulted in the identification of a total of 9607 ha as potential $HNV_{forests,}$ from which 1999 ha corresponded to $HNV_{forest}$ maximum categories and 7608 ha to $HNV_{forest}$ minimum areas in our study area (corresponding to ca. 45%, 9% $HNV_{forest}$Max and 36% $HNV_{forest}$Min, of the total forest area, respectively; Figure 9, Table 9). From the $HNV_{forest}$ area, 58.58% was found to be included in group 1, with remaining 41,41% included in group 3. When considering $HNV_{forest}$ maximum, 41,13% were included in group 1 and 58,87 were included in group 3. Regarding $HNV_{forest}$ minimum categories, 63,17 % of $HNV_{forest}$ areas were included in group 1 and 36,83% in group 3.

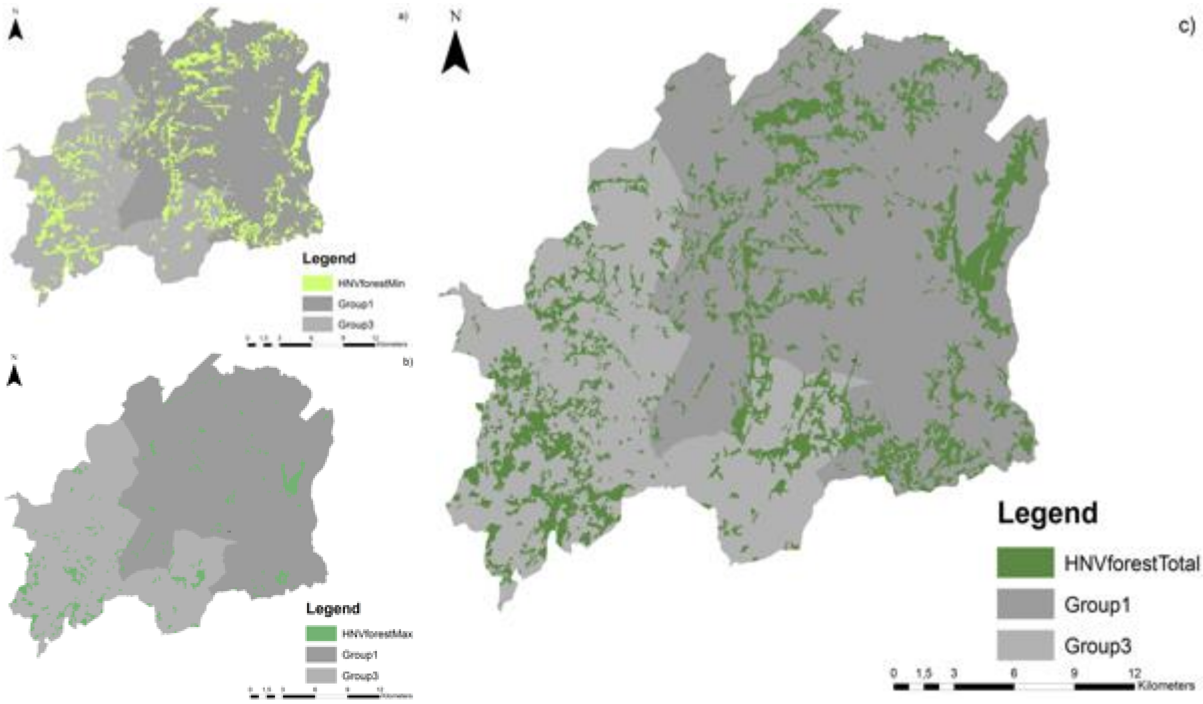


**Figure 9.** Distribution of $HNV_{forest}$ Min (a), Max (b) and Total (c) categories across the parish groups categorized has HNV. $HNV_{forest}$ minimum includes land-cover classes with higher potential to constitute $HNV_{forests}$. $HNV_{forest}$ maximum includes categories with lower nature value.

Forests dominated by other cork species and other broadleaf species contributed the most to the extent of HNV forests in the study area (ca. 35,79 %), followed by forests dominated by other cork species (ca. 22,80 %) and forests dominated by other oak species with coniferous species (ca. 10,90 %), all of which classified as $HNV_{forest}$ Min.

**Table 9.** High Nature Value forest Minimum (Min), Maximum (Max), Total and relation to the Utilised Agricultural Area (UAA) per parish group.

| Parish Groups | $HNV_{forest}$ (ha) | | $HNV_{forest}$ Total (ha) | UAA (ha) | $HNV_{forest}$/UAA (n.a.) |
|---|---|---|---|---|---|
| | Min | Max | | | |
| Group 1 | 4806.26 | 822.37 | 5628.63 | 11230.02 | 0.50 |
| Group 3 | 2802.51 | 1176.75 | 3979.36 | 10963.97 | 0.36 |

By overlaying $HNV_{forest}$ maps with areas under legal protection included in our study area, a total of 47,18 % of total $HNV_{forest}$ was found to be within protected areas (Figure 10). Whilst the majority of these areas were included in the Peneda-Gerês National Park (77,22%; PTCON0001, PTZPE0002), other areas were found to be included in 'Corno do Bico' Protected Landscape (18,33%; PTCON0040) and Lima river (4,44%; PTCON0020).

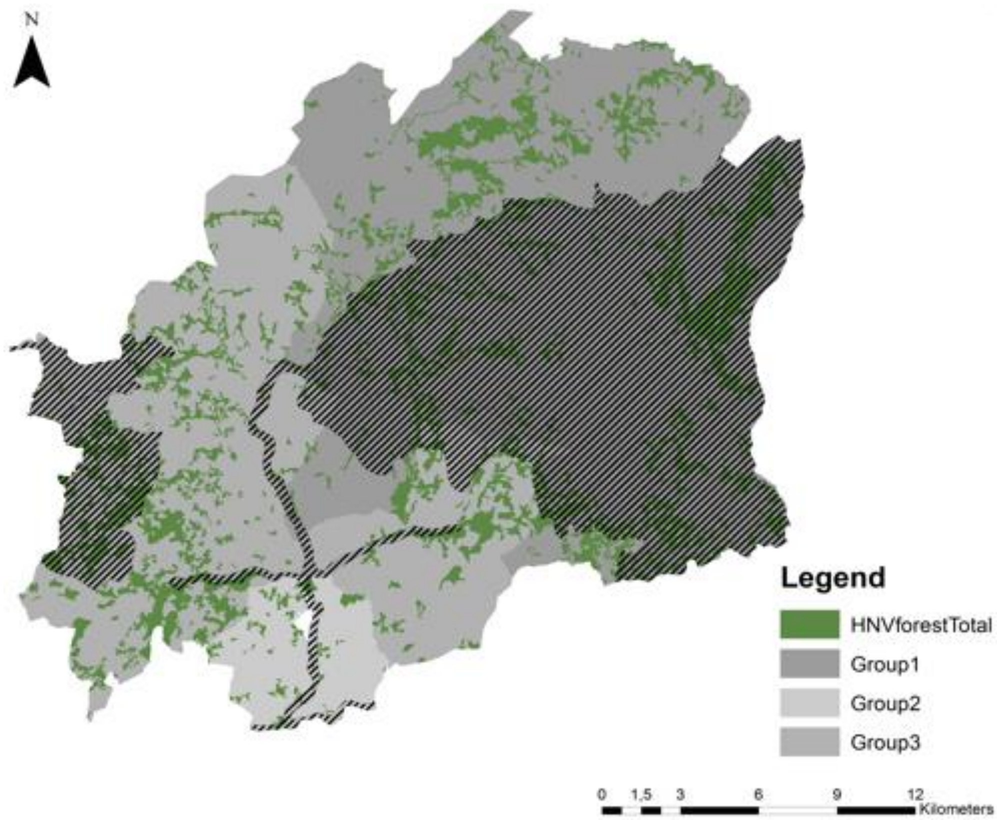


**Figure 10.** Distribution of $HNV_{forests}$ across all three parish groups inside and outside protected areas.

When considering only $HNV_{forest}$ Min, ~48,99 % of the area is included within and 51,01 % outside of protected areas, respectively (Figure 11, Table 10). Similarly, the majority of these forests are included in the Peneda-Gerês National Park (79,70%), followed by 'Corno do Bico' Protected Landscape (17,03%) and lastly Lima river (3,28%). Regarding only $HNV_{forest}$ Max categories, 44,36% of the areas is included within protected areas (79,65 % in the Peneda-Gerês National Park, 14,60% in 'Corno do Bico' and 5,75% in the Lima River), whereas 55,64% is outside these areas.

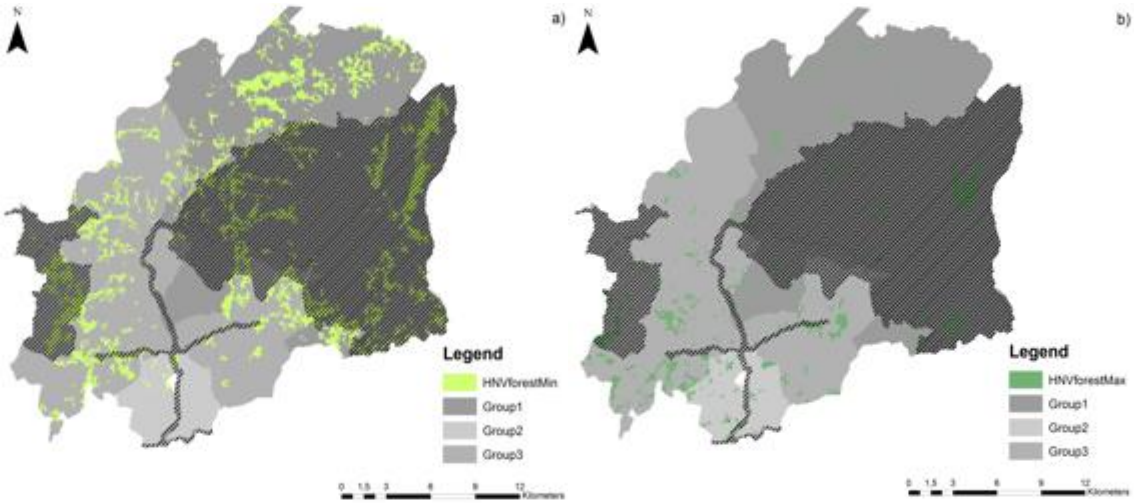


**Figure 11.** Distribution of $HNV_{forests}$ Min (a) and Max (b) areas across parish groups inside and outside areas with special protection.

**Table 10.** High Nature Value forest Minimum, $HNV_{forest}$ Total, Minimum and Maximum, inside and outside protected areas in hectares (ha) per parish groups.

| Parish Groups | Protected Areas | | | Outside Protected Areas | | |
|---|---|---|---|---|---|---|
| | $HNV_{forest}$Min (ha) | $HNV_{forest}$Max (ha) | HNVforest Total (ha) | $HNV_{forest}$Min (ha) | $HNV_{forest}$Max (ha) | HNVforest Total (ha) |
| Group 1 | 2852.88 | 613.14 | 3466.02 | 1953.38 | 209.23 | 2162.61 |
| Group 3 | 884.19 | 250.72 | 1134.91 | 1918.32 | 926.03 | 2844.35 |

## 3.4. Discussion

### 3.4.1. Assessment of High Nature Value forests in Rio Vez Watershed

The $HNV_{forest}$ concept builds on the relevance of management practices for the maintenance of high biodiversity levels and thus the assessment of these areas has been encouraged in the context of EU rural development policies (IEEP, 2007). However, the identification of these areas throughout Europe has been delayed when compared to the mapping of HNV farmland areas (Scottish Government, 2011). Here, we implemented a spatially explicit methodological framework to assess the extent and location of $HNV_{forests}$, using the Rio Vez Watershed, a rural area located in northern Portugal, as our study-area. Considering the complexity of forest ecosystems, different forest dimensions which affect forest biodiversity and function were included in the applied framework. These dimensions included forest composition and structure, management practices and landscape elements.

The application of this methodology allowed the identification of extensively managed forest patches where the occurrence of natural forest processes allows biodiversity support and the provision of ES. Overall, our results highlighted the eastern region of the Rio Vez Watershed as exhibiting higher $HNV_{forest}$ potential (group 1; *cf.* Figure 8). Group 1 included areas composed by larger landscape patches with irregular edges suggesting a more natural landscape (Bell, 1999, Ode *et al.*, 2009). Additionally, higher mean shape index in forest patches in these areas suggest lower anthropogenic reshaping (O'Neill *et al*., 1988). The civil parishes included in this cluster were found to be located in areas with higher physical constraints, reflected as higher slopes and larger mean distance between forest and urban patches. These characteristics conditioned accessibility and consequently the occurrence of anthropogenic disturbance in these areas, and therefore underlie the higher nature value (EEA, 2014, Yaroshenko *et al*., 2001). Similarly, areas within group 3 were characterized by larger landscape patches with irregular edges and high values for forest mean shape index. However, the proximity of these areas to larger urban regions resulted in the simplification of the landscape in comparison to areas included in group 1. Nevertheless, the characteristics of the landscape paired with the cover of $HNV_{forest}$ categories in the parishes included in this cluster support the potential High Nature Value of these areas.

Lastly, group 2 was characterized by smaller landscape patches whit regular edges and shape suggesting higher levels of urbanization. High accessibility of these areas, measured as slope values and distance between forest and urban patches, enables anthropogenic disturbance and results in higher disturbance levels.

Therefore, even though $HNV_{forest}$ land-cover categories were included in group 3, the overall characteristics of these areas suggest less natural forests (non-$HNV_{forests}$).

Shannon Eveness Index (SEI) values were higher in non-$HNV_{forest}$ areas and lower in $HNV_{forest}$ areas. This is likely a result of the higher fragmentation of the landscape in the parishes included in cluster 2. This fragmentation resulted in a higher number of smaller patches of different land-cover types within the landscape. Whereas, areas with HNV potential are characterized by larger forest and farmland patches and smaller urban areas resulting in an uneven distribution of land-covers within the landscape.

Due to their characteristics, some of the $HNV_{forest}$ categories are often included in protected areas (Petrontino and Fucilli, 2013). Particularly, $HNV_{forest}$ Min categories that targeted natural and semi-natural forests classes, reflecting higher biodiversity value (Winter, 2012). However, our results have shown that the majority of $HNV_{forest}$ Min categories are outside of protected areas. The contribution of HNV outside protected areas in terms of both biodiversity and ES provision suggests that there is a need to invest in the protection of these forest patches.

When taking into account the extent of anthropogenic impact in European forests that resulted in the loss of forest area and connectivity resulting in the fragilization of these ecosystems, it is necessary to prioritize areas where management regime allows the maintenance of natural forest function. In order to do so, selected indicators underline the importance of compositional and structural features that result from more extensive management practices as well as spatial constrains that condition continued intensive practices in these areas. Landscapes elements were also considered as they provide information regarding biodiversity maintenance.

### 3.4.2. Implications for the assessment of High Nature Value forests in the EU countryside

The use of this multi-criteria framework, adapted from the methodological framework proposed by Lomba *et al.* (2015) targeting the assessment of High Nature Value farmlands, using reliable indicators that can provide information regarding different forest dimensions, has been proven useful in the assessment of $HNV_{forest}$ extent.

The indicator selection was based on indicator suitability (measure as the number of times an indicator has been referred in previous studies focused on forest naturalness and/or habitat quality) and the existence of spatial data with good resolution grant this framework the flexibility that allows its adaptation and use in other European areas (See Chapter II). Besides the assessment of $HNV_{forest}$ extent, this methodology also allows the continued monitoring of these areas. The use of this framework will depend on the availability of datasets with good spatial and temporal resolution throughout European Union MS. However, the flexibility of this approach should allow the adaptation of this framework for different regions thus contributing for the mapping and assessment of these forests throughout Europe. The distinction of areas according to their HNV potential represents a step forward in the mapping of these areas as it allows the prioritization of areas with the highest potential, which is essential in the context of the payment schemes devised in the context of European RDP’s (Regulation (EU) No

1305/2013).

Even though this is a preliminary analysis, results are promising. However, the application of this framework in other regions with different socio-ecological contexts is essential to determine the flexibility and sensitivity of the approach and of the selected indicators. In addition, the proposed methodology, particularly the definition of minimum and maximum $HNV_{forest}$ categories, will imply that land-use classes are analysed according their nature value. Nevertheless, the application of this framework has the potential to contribute to the comparison between $HNV_{forest}$ extent in different regions across the EU countryside. Further, implementing such framework considering scenarios of land use may inform on how policy changes may impact biodiversity levels and the provision of ES in such areas.

Even though the utilization of this framework may be effective for the assessment of HNV forests, the availability of sufficient data at European scale is fundamental for its implementation. Therefore, the creation of a European data network is essential to the identification and monitoring of HNV forests and for the development and implementation of measures that allow the protection of the species and habitats of conservation concern typically present in these areas.

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# Chapter IV. Discussion and Future Perspectives

Rural Development Policies have among others, the aim of protecting and enhancing HNV farming and forestry systems in the European countryside (Council Decision 2006/144/EC). HNV landscapes are often located in marginal areas where natural limitations to production (such as the presence of steep slopes) have prevented intensification of agricultural and forestry management practices. Even though these areas are characterized by their low potential for provisioning ecosystem services, they are thought to have high potential to contribute to regulation and cultural ES (Hagyo *et al*., 2015).

The assessment of measures undertaken within Rural Development Policies greatly rely on the ability to quantify HNV areas extent and condition across Member State (MS). However, several factors hamper the identification and mapping of such areas, particularly High Nature Value forests, in the European countryside. Amongst these factors, is the complexity of the concept itself paired with the lack of a flexible common methodology that allows targeting such areas throughout European landscapes (Petrontino and Fucilli, 2013). Besides that, the lack of spatially-explicit Europe-wide datasets, with limited thematic, spatial and temporal resolutions constrain the development of suitable approaches to target the diversity of forests considered to exhibit high nature value (IEEP, 2007). These limitations resulted in the inability to determine not only the areas of the EU where HNV forests exist but also where they may contribute to the wider deliver of ES in the context of the social-ecological sustainability.

Recently, the need to develop and test suitable indicators that can inform on the nature value of forests has been highlighted. These indicators need to, not only to express forest naturalness, but also to meet relevant criteria including measurability, specificity and reliability (Niemeijer and de Groot, 2008). Through extensive bibliographical search, we found that ecological indicators are widely used in the assessment of forest naturalness and/or habitat quality (See Chapter II). Our results pinpoint that the usage of specific indicators is often driven by the availability (access) of the data, rather than on their informative character (*cf.* Figure 3). Thus, the existence of cost-effective methods to collect information regarding forest structure and landscape elements seems to foster a preference for using certain groups of indicators in detriment to others. Further, the application of such indicators across Europe, at different scales of analysis, suggest that they are widely use and replicable which further supports the frequency of their use. As so, indicators that can be derived through land cover data at the European scale can provide useful information regarding different forest naturalness dimensions, particularly landscape and structure. Composition indicators assessed through land cover or forest inventory data are also essential for $HNV_{forests}$ assessment. Management indicators, particularly those linked to accessibility, can be assessed through digital evaluation models and land cover maps and are also fundamental in the mapping of these areas.

The common use of naturalness and/or habitat quality indicators in the assessment of different ES types suggests an acknowledged connection between naturalness and ecosystem services provision. As $HNV_{forests}$ are less productive than similar areas where intensive management strategies are applied, provisioning services are less relevant when compared to regulating and cultural services (Hagyo *et al*., 2015). Structure indicators provide key information regarding forest functions and therefore are the most used in the assessment of provisioning, regulating and support services. Due to the link between cultural services and personal preferences regarding landscape and forest management, landscape and management indicators are more commonly used in the assessment of this service type.

The need for a flexible methodology based on multiple criteria using different sets of indicators for $HNV_{forests}$ assessment was previously claimed (*e.g.* EEA, 2014, Petrontino and Fucilli, 2013). Here, a framework based on different sets of indicators expressing distinct dimensions of forests naturalness was adapted from (Lomba *et al*., 2015) research developed and tested for HNV farmlands. Overall, selection of spatially-explicit indicators was based on their use in previous research, their suitability to inform on different dimensions of forest naturalness (landscape, composition, structure, management and environmental) and data availability, criteria that contributes to the so-needed applicability and flexibility of such an approach to be implemented across European rural landscapes (EEA, 2014). The proposed methodological framework allowed the identification of forests with higher potential to exhibit HNV value within a rural area in North-western Portugal. Further, it enabled the discrimination of areas with distinct nature value, which can constitute a step-forward towards the prioritization of areas with higher HNV potential, essential in the context of the Rural Development and Environmental Policies in the EU. Minimum $HNV_{forest}$ areas, included only land cover classes made up primarily of HNV land and Maximum $HNV_{forest}$ areas that included all classes with some HNV land. The use of cluster analysis allowed the identification of parish groups according to their HNV potential. The application of this framework allowed the identification of parish groups with high HNV potential are characterized by larger landscape patches with irregular edges in areas with higher physical constrains suggesting lower levels of anthropogenic disturbance and higher naturalness. Contrastingly, areas composed by smaller landscape patches with regular edges and high accessibility were also identified. These characteristics suggest that these areas are subjected to higher levels of anthropogenic disturbance and, consequently, are less natural (non-$HNV_{forests}$).

As $HNV_{forest}$ categories, in particular $HNV_{forest}$ Min categories, target natural and semi-natural forest classes reflecting higher biodiversity value (Winter, 2012), these forests are often included in protected areas (Petrontino and Fucilli, 2013). However, our results have shown that the majority of $HNV_{forest}$ Min categories are outside of protected areas. Our results have shown that, even though a lot of the $HNV_{forest}$ patches in our study area were located within protected areas, the amount of $HNV_{forests}$ outside these areas is significant, suggesting the need for protection of $HNV_{forest}$ patches outside protected areas.

Although promising, there is still room for improving this framework. Overall, indicators should be further tested for their suitability to be applied to other forest types, which could be done by implementing such approach to different socio-ecological contexts. In such a context, the classification as minimum and maximum $HNV_{forest}$ categories will be established according specific forest types and regional characteristics. Regardless, the application of the proposed framework can potentially contribute to the assessment of HNV extent in the European countryside. Further, when coupled with different land-use scenarios, this methodological approach may provide key information regarding the impact of political decisions on biodiversity and ecosystem service provision in rural Europe.

In order to maximize the effectiveness of $HNV_{forest}$ assessment and monitoring in Europe, efforts should include the creation of a common European database enabling the fundamental exchange of data with sufficient thematic, temporal and spatial resolution between the different European Union member states.

## 4.1. References

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# Appendices

**Appendix I.** Database including a series of articles published in scientific journals, book chapters, conference proceedings and project reports, between 1985 and 2016 relative to forest naturalness and/or habitat quality used within CS1. Overview of indicators that can potentially be used in the assessment and/or mapping of High Nature Value forests ($HNV_{forests}$). This table also includes information regarding the location and scale of the studies, whether they presented a spatial component, if they focused directly on High Nature Value (HNV), the intensity of management in the study area as well as all indicators used in the study distributed within six groups: Landscape, Composition, Structure, Management and Environmental and Others. These indicators were analysed following a presence/absence analysis (presence, 1; absence, 0).

| Reference | Date of publication | Country | Scale | Spatially-explicit | HNV | Intensity of Management | Landscape Indicators | | | | | | | | | | | | | Composition Indicators | | | | | | | | | | | Structure Indicators | | | | | | | | | | Management Indicators | | | | | | | Environmental Indicators | | | | | | Other Indicators |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Natural Disturbance/ Regeneration | Naturalness | Landscape Fragmentation | Acessibility | Landscape Patterns | Protected Forests | Important Bird Areas | Important Plant Areas | Number of Habitat types | Protected Areas | Adjacent land-use | Potential Natural Vegetation | Slope | Tree Species Composition | Species Diversity | Microhabitats | Deadwood | Understory | Species Composition | Exotic Species | Rare/Threatened Species | Proportion of Native Trees | Endangered Vegetation Types | Genetic Resources | Tree Size (Diameter, Volume, Height) | Stand structure (horizontal and vertical) | Deadwood | Forest age structure | Canopy Closure | Old Growth Woodland | Tree Species Composition | Patch Structure | Understory | Species Composition | Deadwood | Forest age structure | Management regime | Forest health (habitat quality) | Specially Shaped Trees | Acessibility | Naturalness | Slope | Elevation | Soil conditions | Water Quantity | Precipitation | Temperature | |
| Kuuluvainen *et al*., 1996 | 1996 | Finland | Stand | 0 | 0 | Managed, unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Uutera *et al*., 1996 | 1996 | Finland, Russia | Stand | 0 | 0 | Managed, sustainably managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Linder *et al*., 1997 | 1997 | Sweden | Stand | 0 | 0 | Unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Stork *et al*., 1997 | 1997 | NA | Forest Management Unit | 0 | 0 | Sustainably managed | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Kuuluvainen *et al*., 1998 | 1998 | Russia | Stand | 0 | 0 | Unmanaged | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Schnitzler and Borlea, 1998 | 1998 | France | Stand | 0 | 0 | Managed | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Honnay* et al*., 1999* | 1999 | Belgium | Stand | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Noss, 1999 | 1999 | NA | Stand | 0 | 0 | Managed | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | Landscape | | | | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Trass *et al*., 1999 | 1999 | Estonia | Stand | 0 | 0 | Unmanaged | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Lindenmayer *et al*., 2000 | 2000 | NA | Landscape | 0 | 0 | Sustainably managed | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Angelstam and Andersson, 2001 | 2001 | Sweden | Landscape | 0 | 0 | NA | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Angelstam *et al*., 2001 | 2001 | EU | Tree | 0 | 0 | Sustainably managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | | Stand | | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | Landscape | | | | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Boncina, 2001 | 2001 | Slovenia | Stand | 0 | 0 | Sustainably managed | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Larsson, 2001 | 2001 | EU | National/regional | 0 | 0 | Sustainably managed | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | | Landscape | | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | | Stand | | | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Neumann and Starlinger, 2001 | 2001 | Austria | Stand | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 |
| Yaroshenko *et al*., 2001 | 2001 | Russia | Landscape | 1 | 0 | Unmanaged | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| Nilsson *et al*., 2002 | 2002 | Sweden | Stand | 0 | 0 | Sustainably managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Uotila *et al*., 2002 | 2002 | Finland, Russia | Stand | 0 | 0 | Managed, unmanaged | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gotmark and Thorell, 2003 | 2003 | Sweden | Landscape | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Leskinen *et al*., 2003 | 2003 | NA | NA | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MCPFE, 2003 | 2003 | EU | NA | 0 | 0 | Sustainably managed | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Mendoza and Prabhu, 2003 | 2003 | NA | NA | 0 | 0 | Sustainably managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Angelstam *et al*., 2004 | 2004 | Sweden | Stand | 1 | 0 | Sustainably managed | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kurlavicius *et al*., 2004 | 2004 | Estonia, Latvia, Lithuania | Stand | 0 | 0 | Sustainably managed | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Onaindia *et al*., 2004 | 2004 | Spain | Stand | 0 | 0 | Unmanaged, sustainably managed, managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Commarmot *et al*., 2005 | 2005 | Switzerland, Ukraine | Stand | 0 | 0 | Managed, unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Langanke *et al*., 2005 | 2005 | Austria | Landscape | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Saudyté *et al*., 2005 | 2005 | Lithuania | Stand | 0 | 0 | Managed, sustainably managed, unmanaged | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| von Oheimb *et al*., 2005 | 2005 | Germany | Stand | 0 | 0 | Sustainably managed | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bartha *et al*., 2006 | 2006 | Hungary | Stand | 0 | 0 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| EEA, 2006 | 2006 | EU | Landscape | 0 | 0 | Sustainably managed | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Spanos *et al*., 2006 | 2006 | NA | National/regional | 0 | 0 | Sustainably managed | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | Landscape | | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | | Stand | | | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| IEEP, 2007 | 2007 | EU | National/regional | 0 | 1 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nielsen *et al*., 2007 | 2007 | Denmark | Stand | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Yermokhin *et al*., 2007 | 2007 | Belarus, Poland | Landscape | 1 | 0 | NA | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| Branquart *et al*., 2008 | 2008 | Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Finland, France, Greece, Italy, Lithuania, Netherlands, Norway, Portugal, Romania, Slovenia, Spain, Sweden, Switzerland, UK | Stand | 0 | 0 | Managed | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Burrascano *et al*., 2008 | 2008 | Italy | Stand | 0 | 0 | Managed, unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cantarello and Newton, 2008 | 2008 | Itay, UK | Forest Management Unit | 0 | 0 | Sustainably managed | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dimalexis *et al*., 2008 | 2008 | Greece | Landscape | 1 | 1 | NA | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Juutinen *et al*., 2008 | 2008 | Finland | Stand | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Luque and Vainikainen, 2008 | 2008 | Finland | Regional | 1 | 0 | Managed, sustainably managed | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Roberge *et al*., 2008 | 2008 | Lithuania, Poland, Sweden | Stand | 0 | 0 | Managed, sustainably managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Smith *et al*., 2008 | 2008 | Ireland | Stand | 0 | 0 | Sustainably managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Svoboda and Pouska, 2008 | 2008 | Czech Republic | Stand | 0 | 0 | Unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BirdLife International, 2009 | 2009 | Bulgaria, Romania | NA | 1 | 0 | NA | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Burrascano *et al*., 2009 | 2009 | Italy | Stand | 0 | 0 | Managed, unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| Liira and Sepp, 2009 | 2009 | Estonia | Stand | 0 | 0 | Managed, sustainably managed, unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ode *et al*., 2009 | 2009 | NA | Landscape | 0 | 0 | NA | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Visnjic *et al*., 2009 | 2009 | Bosnia and Herzegovina | Stand | 0 | 0 | Unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Brunet *et al*., 2010 | 2010 | EU | Stand | 0 | 0 | Managed, unmanaged | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Geburek *et al*., 2010 | 2010 | NA | Landscape | 0 | 0 | Managed, unmanaged | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Keeton *et al*., 2010 | 2010 | Ukraine | Stand | 0 | 0 | Sustainably managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Liira and Kohv, 2010 | 2010 | Estonia | Stand | 0 | 0 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| Lõhmus and Kraut, 2010 | 2010 | Estonia | Stand | 0 | 0 | Managed, unmanaged | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Blasi *et al.*, 2010 | 2010 | Italy | Stand | 0 | 0 | Sustainably managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Moravcík *et al.*, 2010 | 2010 | Slovakia | Stand | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Renetzeder *et al.*, 2010 | 2010 | EU | Landscape | 1 | 0 | NA | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Veen *et al.*, 2010 | 2010 | Romania, Bulgaria | NA | 0 | 0 | Unmanaged | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wallenius *et al.*, 2010 | 2010 | Finland, Netherlands, Poland, Russia, Sweden | Stand | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Winter *et al.*, 2010 | 2010 | Germany | Landscape | 0 | 0 | Manage, unmanaged | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Blasi *et al.*, 2011 | 2011 | Italy | NA | 1 | 0 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Brumelis *et al.*, 2011 | 2011 | NA | NA | 0 | 0 | NA | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maesano *et al.*, 2011 | 2011 | Italy | National | 1 | 0 | NA | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Palo *et al.*, 2011 | 2011 | Estonia | Stand | 0 | 0 | Unmanaged, sustainably managed, managed | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Scottish Government, 2011 | 2011 | Scotland | NA | 0 | 1 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Winter *et al.*, 2011 | 2011 | EU, USA | NA | 0 | 0 | NA | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Duncker *et al.*, 2012 | 2012 | Germany | Forest Management Unit | 0 | 0 | Managed, unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Kucbel *et al.*, 2012 | 2012 | Slovakia | Stand | 0 | 0 | Sustainably managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mäkelä *et al.*, 2012 | 2012 | NA | Stand | 0 | 0 | Sustainably managed | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| McRoberts *et al.*, 2012 | 2012 | USA | Stand | 0 | 0 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | EU | | | | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Merganič *et al.*, 2012 | 2012 | Slovakia | Stand | 1 | 0 | Unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Paletto and Chincarini, 2012 | 2012 | Italy | NA | 0 | 0 | NA | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Petritan *et al.*, 2012 | 2012 | Romania | Stand | 0 | 0 | Sustainably managed | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pignatti *et al.*, 2012 | 2012 | Italy | Stand | 0 | 1 | NA | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Winter, 2012 | 2012 | NA | NA | 0 | 0 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Brukas *et al.*, 2013 | 2013 | Lithuania, Sweden | Stand | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Burrascano *et al.*, 2013 | 2013 | NA | Stand | 0 | 0 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 |
| Coote *et al.*, 2013 | 2013 | Ireland | Stand | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 |
| Pătru-Stupariu *et al.*, 2013 | 2013 | Romania | Stand | 1 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Petrontino and Fucilli, 2013 | 2013 | Italy | Landscape | 1 | 1 | NA | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | | Stand | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Barbati *et al.*, 2014 | 2014 | Italy | Stand | 0 | 0 | Sustainably managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| EEA, 2014 | 2013 | EU | NA | 1 | 1 | NA | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Gao *et al.*, 2014 | 2014 | Sweden | Stand | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maesano *et al.*, 2014 | 2014 | Italy | National | 1 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Gao *et al.*, 2015 | 2015 | NA | Stand | 0 | 0 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | | | Landscape | | | | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lombardi *et al.*, 2015 | 2015 | Italy | Stand | 0 | 0 | Unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 |
| Vaz *et al.*, 2015 | 2015 | Portugal | Landscape | 0 | 0 | Unmanaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Bugalho *et al.*, 2016 | 2016 | Portugal | Landscape | 1 | 0 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Kovac *et al.*, 2016 | 2016 | Slovenia | Stand | 0 | 0 | NA | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Stachura-Skierczyńska and Kosiński, 2016 | 2016 | Poland | Stand | 0 | 0 | Managed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

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**Appendix II.** Database including a series of articles published in scientific journals, book chapters, conference proceedings and project reports, between 1985 and 2016 relative to forest ecosystem service provision used within CS1. Overview of indicators that can potentially be useful in the quantification of service provision in forests. This table also includes information regarding the location of the studies and whether they presented a spatial component. Indicators used in the studies were distributed within the four service groups considered by the Millennium Ecosystem Assessment: Provisioning, Regulating, Cultural and Supporting. These indicators were analysed following a presence/absence analysis (presence, 1; absence, 0).

| **Reference** | **Date of Publication** | **Country** | **Spatially-explicit** | **Provisioning** | | | | | | | **Regulating** | | | | | | | | | | | | | | | **Cultural** | | | | | | | | | | | | | | **Supporting** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Precipitation | Canopy closure | Deadwood | Elevation | Natural disturbance/Regeneration | Temperature | Tree size | Tree species composition | Tree size | Slope | Canopy closure | Precipitation | Temperature | Tree species composition | Deadwood | Understory | Elevation | Forest health | Microhabitats | Natural regeneration | Old-growth woodland | Water quantity | Acessability | Canopy closure | Naturalness | Forest age structure | Elevation | Deadwood | Landscape fragmentation | Management regime | Protected Areas | Rare/threatened species | Slope | Temperature | Tree size | Tree species composition | Deadwood | Forest age structure | Understory |
| Harmon *et al.*, 1986 | 1986 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Krankina and Harmon, 1995 | 1995 | Canada, Russia, USA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Guo *et al.*, 2000 | 2000 | China | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lindhagen and Hörnsten, 2000 | 2000 | Sweden | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Conti and Cecchetti, 2001 | 2001 | Italy | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Holub *et al.*, 2001 | 2001 | USA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MCPFE, 2003 | 2002 | EU | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Kraigher *et al*., 2002 | 2002 | Slovenia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Boa, 2004 | 2004 | NA | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jaarsveld *et al*., 2005 | 2005 | South Africa | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chan *et al*., 2006 | 2006 | USA | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Scarth *et al*., 2006 | 2006 | Australia | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Egoh *et al*., 2008 | 2008 | South Africa | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Grêt-Regamey *et al*., 2008 | 2008 | Switzerland | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Jim and Chen, 2008 | 2008 | China | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kalacska *et al*., 2008 | 2008 | Costa Rica & Mexico | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Li and Ren, 2008 | 2008 | China | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Luyssaert *et al*., 2008 | 2008 | NA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Willemen *et al*., 2008 | 2008 | Netherlands | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chen *et al*., 2009 | 2009 | China | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Escobedo and Nowak, 2009 | 2009 | Chile | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nelson *et al*., 2009 | 2009 | USA | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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| Reyers *et al.*, 2009 | 2009 | South Africa | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Shi *et al.*, 2009 | 2009 | China | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chisholm, 2010 | 2010 | USA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ditt *et al.*, 2010 | 2010 | Brasil | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Eigenbrod *et al.*, 2010 | 2010 | UK | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pert *et al.*, 2010 | 2010 | Australia | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Raudsepp-Hearne *et al.*, 2010 | 2010 | Canada | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wendland *et al.*, 2010 | 2010 | Madagascar | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Willemen *et al.*, 2010a | 2010 | Netherlands | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Willemen *et al.*, 2010b | 2010 | Netherlands | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bai *et al.*, 2011 | 2011 | China | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Deng *et al.*, 2011 | 2011 | China | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Escobedo *et al.*, 2011 | 2011 | USA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sherrouse *et al.*, 2011 | 2011 | USA | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bastian *et al.*, 2012 | 2012 | Germany | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Duncker *et al.*, 2012 | 2012 | Germany | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Edwards *et al.*, 2012 | 2012 | Austria, Finland, Germany, Norway, Portugal, Spain, Sweden, Switzerland, UK | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Laterra *et al.*, 2012 | 2012 | Argentina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gamfeldt *et al.*, 2013 | 2013 | Sweden | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Garcia-Gonzalo *et al.*, 2013 | 2013 | Portugal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Grêt-Regamey *et al.*, 2013 | 2013 | Switzerland | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gulickx *et al.*, 2013 | 2013 | Netherlands | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hengeveld *et al.*, 2015 | 2015 | Netherlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rodríguez and Kouki, 2015 | 2015 | Finland | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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**Appendix III.** Overview of indicators that can potentially be used in the assessment and/or mapping of High Nature Value forests ($HNV_{forests}$). All indicators included in this table have been reported as useful or used by one or more authors in the assessment of forest naturalness and/or habitat quality and therefore can potentially be helpful in the identification of $HNV_{forests}$ defined as "all natural forests and those semi-natural forests in Europe where the management (historical or present) supports a high diversity of native species and habitats, and/or those forests which support the presence of species of European, and/or national, and/or regional conservation concern" (IEEP, 2007). These indicators were collected from a series of articles published in scientific journals, book chapters, conference proceedings and project reports, between 1985 and 2016, through a systematic search using two major databases (ISI Web of Science and Scopus) with different combinations of relevant search terms. All reported indicators, with the exception of those reported only in one source, were distributed, according to their description and use in the original references, within five indicator groups: L, landscape; C, composition; S, structure; M, management; E, environmental. As landscape indicators we included all indicators that informed on landscape metrics, composition and structure. Within Composition all indicators which express the compositional features or that were used to inform on the composition of the patch were considered. As Structure indicators we considered all indicators expressing the structure of the stand. Management indicators comprehended all indicators used to express the type/intensity of management. Lastly, as environmental indicators we considered indicators disclosing abiotic characteristics of the forest ecosystems considered across case studies. As different authors use different concepts towards analogous indicators, after their collection, indicators were regrouped and renamed. Information regarding all the different concepts used by different authors is also included in this table.

| Indicators | L | C | S | M | E | Associated concepts |
|---|---|---|---|---|---|---|
| Accessibility | | | | | | Road density, elevation, remoteness from access, remoteness from settlements, distance to roads, distance to urban areas, limited access areas, walking distance to village |
| Adjacent land-use | | | | | | Adjacent land-use, landscape use |
| Important Bird Areas | | | | | | Important bird areas |
| Important Plant Areas | | | | | | Important plant areas |
| Landscape fragmentation | | | | | | Fragmentation and connectivity indices, interpatch distance, presence of corridors, nearest neighbour, large patches of forest, proximity to forest patches, number of woodland patches |
| Landscape patterns | | | | | | Patch size distribution, fractal dimension, edge density, shape index, perimeter-area ratio, high spatial heterogeneity |

| | | | | | | |
|---|---|---|---|---|---|---|
| Natural disturbance | | | | | | Alteration of natural disturbance regimes (frequency, intensity, patterns), presence of natural regeneration, natural rejuvenation, type of regeneration |
| Naturalness | | | | | | Human impact, human influence, undisturbed areas, signs of natural ecological processes, signs of human activity, vegetation integrity, degree of naturalness, hemeroby, naturalness of actual tree species composition |
| Number of habitat types | | | | | | Number and type of habitats |
| Potential natural vegetation | | | | | | Potential natural vegetation, comparison of current with potential natural vegetation |
| Protected forests | | | | | | Protected forests, natural forest reserves |
| Protected areas | | | | | | Protected areas |
| Dominant trees | | | | | | Dominant tree species, dominant forest species, main forest types, main tree species |
| Endangered vegetation types | | | | | | Endangered vegetation types |
| Exotic species | | | | | | Ratio of exotic species to native species in community, presence of non-native species, area of forest and other wooded land dominated by introduced tree species, presence of introduced species |
| Genetic resources | | | | | | Genetic resources, genetics forest reserves |
| Microhabitats | | | | | | Occurrence bryophyte species, occurrence of lichen species, trees providing micro-habitats, moss coverage, lichen coverage, occurrence of microsites, number of microhabitat trees |
| Proportion of native trees | | | | | | Proportion of native trees, mean number of native tree species |
| Rare species | | | | | | Rare natural vegetation cover, occurrence/number of threatened forest species, rare forest-dependent species, rare broadleaf species, presence of native/site-indigenous species |
| Species composition | | | | | | Species composition, specific composition |
| Species diversity | | | | | | Total species richness, mean species richness/ha, Shannon and Weaver index |
| Tree species composition | | | | | | Tree species composition, tree species proportion |
| Understory | | | | | | Percentage of shrubs cover, herb cover, ground vegetation, number of ground vegetation species, graminoid, coverage of grasses, herb and grass species |
| Canopy closure | | | | | | Canopy closure, canopy openness, canopy cover, crown canopy cover, gaps in canopy |
| Deadwood | | | | | | Presence and abundance of snags and down logs in various size and decay classes, quality and amount of deadwood, volume of deadwood |
| Forest age structure | | | | | | Age class distribution, stand age, mean age, average age of stand, uneven age structure, patches with uneven-aged structure, varying aged stand |
| Old-growth woodlands | | | | | | Area occupied by old-growth and late-successional stages per patch, presence of old trees, distance to old woodland |
| Patch structure | | | | | | Patch area, edge characteristics (stand shape, ecotone, surrounding habitat), margin shape |
| Stand structure | | | | | | Horizontal structure, horizontal distribution, vertical structure, vertical distribution, tree stand structural complexity (horizontal and vertical), several canopy layers |
| Tree size | | | | | | Diameter class distribution, tree height, volume |
| Forest health | | | | | | Health condition, dieback trees |

| | | | | | | |
|---|---|---|---|---|---|---|
| Management regime | | | | | | Different management types in the study area, information on forest management system, signs of management, forest management |
| Specially shaped trees | | | | | | Specially shaped trees, forked living trees, multi-stemmed trees |
| Elevation | | | | | | Elevation, digital elevation model, altitude, altitudinal range |
| Precipitation | | | | | | Annual precipitation, mean precipitation, mean monthly precipitation |
| Slope | | | | | | Slope, inclination |
| Soil conditions | | | | | | Soil conditions, soil erodibility, soil physical condition |
| Soil type | | | | | | Soil type |
| Temperature | | | | | | Mean temperature, mean monthly temperature |
| Water quantity | | | | | | Water quantity, presence of water courses, flooded areas, proximity to water, aquifer recharge rate |

## References

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**Appendix IV.** Overview of naturalness and/or habitat quality indicators that can be used in the assessment of different types of ecosystem services defined by the Millennium Ecosystem Assessment (MA, 2005) (P, provision; R, regulation; C, cultural; S, support) in forests. These indicators were collected from a series of articles published in scientific journals, book chapters, conference proceedings and project reports, between 1985 and 2016, through a systematic search using two major databases (ISI Web of Science and Scopus) with different combinations of relevant key-words. All indicators included in this table have been used by one or more authors in the assessment of different types of ecosystem services in forests. Only those that can be simultaneously used in the assessment of High Nature Value Forests ($HNV_{forests}$) have been selected. Information regarding the fundamental reasons, or rationale, for the potential use of these naturalness and/or habitat quality indicators in the assessment and/or quantification of ecosystem service provision is also included in this table.

<table>
<tr><th rowspan="2">Indicators</th><th colspan="4">Ecosystem Services</th><th rowspan="2">Rationale</th></tr>
<tr><th>P</th><th>R</th><th>C</th><th>S</th></tr>
<tr><td>Accessibility</td><td></td><td></td><td></td><td></td><td>Influences forest attractiveness for recreation (Grêt-Regamey et al., 2013), therefore this indicator is used by some authors to estimate the recreational value (Chan et al., 2006, Willemen et al., 2010b, Grêt-Regamey et al., 2013).</td></tr>
<tr><td rowspan="3">Canopy closure</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td>Informs on the amount of wood harvested (Grêt-Regamey et al., 2013).</td></tr>
<tr><td>Influences air pollutant removal (Jim and Chen, 2008, Escobedo and Nowak, 2009, Grêt-Regamey et al., 2013) and water regulation water regulation (Li and Ren, 2008).</td></tr>
<tr><td>Affects the forest recreation value (Lindhagen and Hörnsten, 2000, Willemen et al., 2008, Willemen et al., 2010a, Willemen et al., 2010b, Grêt-Regamey et al., 2013).</td></tr>
<tr><td rowspan="4">Deadwood</td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td>Deadwood serves as habitat for several fungi species with commercial interest for their nutritional and medicinal value (Boa, 2004).</td></tr>
<tr><td>Contributes to soil retention and stabilization (Harmon et al., 1986, Kraigher et al., 2002).</td></tr>
<tr><td>People tend to prefer areas with inferior amounts of deadwood due to the accessibility of the location (Lindhagen and Hörnsten, 2000).</td></tr>
<tr><td>Fundamental in nutrient cycling (Harmon et al., 1986).</td></tr>
<tr><td rowspan="2">Dominant trees</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>Used to estimate water provision by some authors (Bai et al., 2011).</td></tr>
<tr><td>The differences in terms of dominant tree species results in deferent water flow regulation, therefore this parameter is used in the quantification of this ecosystem service (Guo et al., 2000). Forest dominant tree species also influence air quality maintenance (Deng et al., 2011).</td></tr>
</table>

| | | | | | |
|---|---|---|---|---|---|
| | | | | | People preference in terms of recreational value is influenced by this parameter (Edwards *et al*., 2012). |
| Elevation | | | | | Used to quantify timber production (Grêt-Regamey *et al*., 2008). |
| | | | | | Used to quantify extreme event prevention (Grêt-Regamey *et al*., 2008). |
| Elevation | | | | | Used to quantify scenic beauty (Grêt-Regamey *et al*., 2008, Sherrouse *et al*., 2011). |
| Forest age structure | | | | | Influences the preference of people in terms of forest recreation (Lindhagen and Hörnsten, 2000, Edwards *et al*., 2012). |
| | | | | | Used as an indicator of the maintenance and enhancement of life cycles (MCPFE, 2003). |
| Forest health | | | | | Forest fire safety degree depends on forest health (Hengeveld *et al*., 2015). |
| Landscape fragmentation | | | | | Used to quantify aesthetical value (Hengeveld *et al*., 2015). |
| Management regime | | | | | People have different preferences recreational wise depending on the type of management that the forest is subjected to (Edwards *et al*., 2012). |
| Microhabitats | | | | | Lichens are commonly used air quality indicators (Conti and Cecchetti, 2001). |
| Naturalness | | | | | Influences recreational value (Chan *et al*., 2006) and tourism (Willemen *et al*., 2008, Willemen *et al*., 2010a, Willemen *et al*., 2010b). |
| Natural regeneration | | | | | Alterations in natural disturbance cycles have shown to lower pollination and, consequently, wild berry production (Rodríguez and Kouki, 2015). |
| Old-growth woodland | | | | | Old-growth woodland areas are global carbon sinks (Luyssaert *et al*., 2008). |
| Precipitation | | | | | Contributes to water provision (Chan *et al*., 2006). |
| | | | | | Affects erosion prevention (Reyers *et al*., 2009), hydrological regulation (Laterra *et al*., 2012) and climate regulation (Shi *et al*., 2009). |
| Protected areas | | | | | Often tourism is focused in these areas (Jaarsveld *et al*., 2005). |
| Rare species | | | | | The presence of rare species contributes to nature appreciation (Raudsepp-Hearne *et al*., 2010). |
| Slope | | | | | Water regulation varies in relation to the slope (Guo *et al*., 2000, Nelson *et al*., 2009). Slope values are used in soil conservation calculations (Li and Ren, 2008). This indicator is also related to climate regulation (Pert *et al*., 2010). |
| | | | | | Related with recreational value (Sherrouse *et al*., 2011). |
| Soil type | | | | | Soil type influences hydrological regulation (Guo *et al*., 2000) and carbon storage (Laterra *et al*., 2012). |
| Temperature | | | | | Used to estimate timber production (Grêt-Regamey *et al*., 2008). |
| | | | | | Used to estimate climate regulation (Shi *et al*., 2009, Bastian *et al*., 2012), also related with occurrence of extreme events (Grêt-Regamey *et al*., 2008). |
| | | | | | Related with scenic beauty (Grêt-Regamey *et al*., 2008). |

| | | | | | |
|---|---|---|---|---|---|
| Tree species composition | | | | | Contributes to wood and food provision (Gamfeldt *et al*., 2013). |
| | | | | | Contributes to climate regulation (Gamfeldt *et al*., 2013). Related with the prevention of extreme events occurrence (Hengeveld *et al*., 2015) and used in hydrological models (Duncker *et al.*, 2012). |
| | | | | | Related with peoples preferences in terms of forest recreational value (Lindhagen and Hörnsten, 2000). |
| Tree size | | | | | Related with the volume of wood harvested (Garcia-Gonzalo *et al*., 2013). |
| | | | | | Used to estimate tree biomass in relation with climate regulation due to carbon storage (Chan *et al*., 2006, Kalacska *et al*., 2008, Bai *et al*., 2011). Tree size, in particular tree height is related with fire-safety (Hengeveld *et al*., 2015). |
| | | | | | Related with peoples preferences in terms of forest recreational value (Lindhagen and Hörnsten, 2000). |
| Understory | | | | | Ground cover contributes to evaporation and thermal balance, climate regulation and regulation of temperatures near the ground, slows down water flows contributing for hydrological regulation, reduces soil erosion, contributes to the occurrence of pollination (Prosser *et al*., 2000, Friedman and Harder, 2004, Petter *et al*., 2013). |
| | | | | | Contributes to nutrient cycling and soil formation (Petter *et al*., 2013). |
| Water quantity | | | | | Related with water flow regulation (Egoh *et al*., 2008). |

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**Appendix V.** Land Cover classes discriminated in the different levels of the COS 2007, correspondence to forest or non-forest classes (n.f.) and the High Nature Value potential of the different forest classes. As non-forest we included all land cover classes not eligible as forests. Minimum HNV$_{forest}$ areas represent areas with high HNV potential and include land cover classes that had primarily HNV value. HNV$_{forest}$ Max classes coincide with areas with moderate HNV potential including all land cover classes that had some HNV value. The distinction between HNV categories was based on the naturalness of forest categories. As Maximum HNV$_{forests}$, forest classes were selected accordingly to the Portuguese agriculture ministry. As Minimum HNV$_{forests}$ were chosen according to the naturalness of forest composition. The Minimum selection includes only the classes of land cover which are made up primarily of HNV land, while the Maximum selection included all classes with some HNV land. As so, the Maximum selection is expected to contain much non-HNV land, whilst the Minimum inevitably would exclude some probable HNV land.

| Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | n.f. | Forests | Non-HNV$_{forests}$ | HNV forests | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Minimum HNV$_{forests}$ | Maximum HNV$_{forests}$ |
| 1 Artificial surfaces | 1.1 Urban fabric | 1.1.1 Continuous urban fabric | 1.1.1.01 Continuous urban fabric predminantly vertical | 1.1.1.01.1 Continuous urban fabric predminantly vertical | x | | | | |
| | | | 1.1.1.02 Continuous urban fabric predominatly horizontal | 1.1.1.02.2 Continuous urban fabric predominatly horizontal | x | | | | |
| | | | 1.1.1.03 Other urban fabric | 1.1.1.03.3 Other urban fabric | x | | | | |
| | | 1.1.2 Discontinuous urban fabric | 1.1.2.01 Discontinuous urban fabric | 1.1.2.01.1 Discontinuous urban fabric | x | | | | |
| | | | 1.1.2.02 Sparse discontinuous urban fabric | 1.1.2.02.1 Sparse discontinuous urban fabric | x | | | | |
| | 1.2 Industrial, commercial and transport units | 1.2.1 Industrial or commercial units | 1.2.1.01 Industry | 1.2.1.01.1 Industry | | | | | |
| | | | 1.2.1.02 Commerce | 1.2.1.02.1 Commmerce | x | | | | |
| | | | 1.2.1.03 Agricultural facilities | 1.2.1.03.1 Agricultural facilities | | | | | |
| | | | 1.2.1.04 Public and private equipments | 1.2.1.04.1 Public and private equipments | x | | | | |
| | | | 1.2.1.05 Energy production infrastructures | 1.2.1.05.1 Renewable energy production infrastructures | x | | | | |
| | | | | 1.2.1.05.2 Non-renewable energy production infrastructures | x | | | | |
| | | | 1.2.1.06 Infrastructures for water reception, treatment and supply for consumption | 1.2.1.06.1 Infrastructures for water reception, treatment and supply for consumption | x | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1.2.1.07 Infrastructures for waste and residual water treatment | 1.2.1.07.1 Infrastructures for waste and residual water treatment | x | | | | |
| | | 1.2.2 Road and rail networks and associated land | 1.2.2.01 Road network and associated land | 1.2.2.01.1 Road network and associated land | x | | | | |
| | | | 1.2.2.02 Rail network and associated land | 1.2.2.02.1 Rail network and associated land | x | | | | |
| | | 1.2.3 Port areas | 1.2.3.01 Sea and river port terminals | 1.2.3.01.1 Sea and river port terminals | x | | | | |
| | | | 1.2.3.02 Shipyards and dry docks | 1.2.3.02.1 Shipyards and dry docks | x | | | | |
| | | | 1.2.3.03 Marinas and fishing docks | 1.2.3.03.1 Marinas and fishing docks | x | | | | |
| | | 1.2.4 Airports | 1.2.4.01 Airports | 1.2.4.01.1 Airports | x | | | | |
| | | | 1.2.4.02 Aerodromes | 1.2.4.02.1 Aerodromes | x | | | | |
| | 1.3. Mine, dump and construction sites | 1.3.1 Mineral extraction sites | 1.3.1.01 Open pit mines | 1.3.1.01.1 Open pit mines | x | | | | |
| | | | 1.3.1.02 Quarries | 1.3.1.02.1 Quarries | x | | | | |
| | | 1.3.2 Dump sites | 1.3.2.01 Landfill | 1.3.2.01.1 Landfill | x | | | | |
| | | | 1.3.2.02 Dumpsters and scraps | 1.3.2.02.1 Dumpsters and scraps | x | | | | |
| | | 1.3.3 Construction sites | 1.3.3.01 Construction sites | 1.3.3.01.1 Construction sites | x | | | | |
| | | | 1.3.3.02 Abandonned sites in artificial territories | 1.3.3.02.1 Abandonned sites in artificial territories | x | | | | |
| | 1.4 Artficial, non-agricultural vegetated areas | 1.4.1 Green urban areas | 1.4.1.01 Parks and gardens | 1.4.1.01.1 Parks and gardens | x | | | | |
| | | | 1.4.1.02 Graveyards | 1.4.1.02.1 Graveyards | x | | | | |
| | | 1.4.2 Sport and leisure facilities | 1.4.2.01 Sport facilities | 1.4.2.01.1 Golf parks | x | | | | |
| | | | | 1.4.2.01.2 Other sport facilities | x | | | | |
| | | | 1.4.2.02 Leisure facilities | 1.4.2.02.1 Camping | x | | | | |
| | | | | 1.4.2.02.2 Other leisure facilities | x | | | | |
| | | | 1.4.2.03 Cultural facilities and historical zones | 1.4.2.03.1 Cultural facilities and historical zones | x | | | | |
| 2 Agricultural areas | 2.1 Arable land | 2.1.1 Non-irrigated annual crops | 2.1.1.01 Non-irrigated annual crops | 2.1.1.01.1 Non-irrigated annual crops | x | | | | |
| | | | 2.1.1.02 Greenhouses and nurseries | 2.1.1.02.1 Greenhouses and nurseries | x | | | | |
| | | 2.1.2 Irrigated annual crops | 2.1.2.01 Irrigated annual crops | 2.1.2.01.1 Irrigated annual crops | x | | | | |
| | | 2.1.3 Rice paddies | 2.1.3.01 Rice paddies | 2.1.3.01.1 Rice paddies | x | | | | |
| | 2.2 Permanent crops | 2.2.1 Vineyards | 2.2.1.01 Vineyards | 2.2.1.01.1 Vineyards | x | | | | |
| | | | 2.2.1.02 Vineyards with orchards | 2.2.1.02.1 Vineyards with orchards | x | | | | |
| | | | 2.2.1.03 Vineyards with olivegroves | 2.2.1.03.1 Vineyards with olivegroves | x | | | | |
| | | 2.2.2 Orchards | 2.2.2.01 Orchards | 2.2.2.01.1 Orchards of fresh fruits | x | | | | |
| | | | | 2.2.2.01.2 Orchards of almonds | x | | | | |
| | | | | 2.2.2.01.3 Orchards of chestnut | x | | | | |
| | | | | 2.2.2.01.4 Orchards of carob | x | | | | |
| | | | | 2.2.2.01.5 Orchards of citric fruits | x | | | | |
| | | | | 2.2.2.01.6 Other orchards | x | | | | |
| | | | 2.2.2.02 Orchards with vineyards | 2.2.2.02.1 Orchards of fresh fruits with vineyards | x | | | | |
| | | | | 2.2.2.02.2 Orchards of almonds with vineyards | x | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 2.2.2.02.3 Orchards of chestnut with vineyards | x | | | | |
| | | | | 2.2.2.02.4 Orchards of carob with vineyards | x | | | | |
| | | | | 2.2.2.02.5 Orchards of citric fruits with vineyards | x | | | | |
| | | | | 2.2.2.02.6 Other orchards with vineyards | x | | | | |
| | | | 2.2.2.03 Orchards with olivegroves | 2.2.2.03.1 Orchards of fresh fruits with olivegroves | x | | | | |
| | | | | 2.2.2.03.2 Orchards of almonds with olivegroves | x | | | | |
| | | | | 2.2.2.03.3 Orchards of chestnut with olivegroves | x | | | | |
| | | | | 2.2.2.03.4 Orchards of carob with olivegroves | x | | | | |
| | | | | 2.2.2.03.5 Orchards of citric fruits with olivegroves | x | | | | |
| | | | | 2.2.2.03.6 Other orchards with olivegroves | x | | | | |
| | | 2.2.3 Olive groves | 2.2.3.01 Olivegroves | 2.2.3.01.1 Olivegroves | x | | | | |
| | | | 2.2.3.02 Olivegroves with vineyards | 2.2.3.02.1 Olivegroves with vineyards | x | | | | |
| | | | 2.2.3.03 Olivegroves with orchards | 2.2.3.03.1 Olivegroves with orchards | x | | | | |
| | 2.3 Pastures and grasslands | 2.3.1 Permanent grasslands | 2.3.1.01 Permanent grasslands | 2.3.1.01.1 Permanent grasslands | x | | | | |
| | 2.4 Heterogeneous agricultural areas | 2.4.1 Annual crops and/or pastures associated to perment crops | 2.4.1.01 Non-irrigated annual crops associated to permanent crops | 2.4.1.01.1 Non-irrigated annual crops associated to vineyards | x | | | | |
| | | | | 2.4.1.01.2 Non-irrigated annual crops associated to orchards | x | | | | |
| | | | | 2.4.1.01.3 Non-irrigated annual crops associated to olivegroves | x | | | | |
| | | | 2.4.1.02 Irrigated annual crops associated to permanent crops | 2.4.1.02.1 Irrigated annual crops associated to vineyards | x | | | | |
| | | | | 2.4.1.02.2 Irrigated annual crops associated to orchards | x | | | | |
| | | | | 2.4.1.02.3 Irrigated annual crops associated to olivegroves | x | | | | |
| | | | 2.4.1.03 Pastures/Grasslands associated to permanent crops | 2.4.1.03.1 Pastures/Grasslands associated to vineyards | x | | | | |
| | | | | 2.4.1.03.2 Pastures/Grasslands associated to orchards | x | | | | |
| | | | | 2.4.1.03.3 Pastures/Grasslands associated to olivegroves | x | | | | |
| | | 2.4.2 Complex crop mosaics and systems | 2.4.2.01 Complex crop mosaics and systems | 2.4.2.01.1 Complex crop mosaics and systems | x | | | | |
| | | 2.4.3 Farmlands with natural and semi-natural areas | 2.4.3.01 Farmlands with natural and semi-natural areas | 2.4.3.01.1 Farmlands with natural and semi-natural areas | x | | | | |
| | | 2.4.4 Agro-forestry systems (SAF) | 2.4.4.01 SAF with non-irrigated annual crops | 2.4.4.01.1 SAF of cork oak with non-irrigated annual crops | x | | | | |
| | | | | 2.4.4.01.2 SAF of evergreen oak with non-irrigated annual crops | x | | | | |
| | | | | 2.4.4.01.3 SAF of other oak species with non-irrigated annual crops | x | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 2.4.4.01.4 SAF of other species with non-irrigated annual crops | x | | | | |
| | | | | 2.4.4.01.5 SAF mixed cork and evergreen oak with non-irrigated annual crops | x | | | | |
| | | | | 2.4.4.01.6 SAF other mixed formations with non-irrigated annual crops | x | | | | |
| | | | 2.4.4.02 SAF with irrigated annual crops | 2.4.4.02.1 SAF of cork oak with irrigated annual crops | x | | | | |
| | | | | 2.4.4.02.2 SAF of evergreen oak with irrigated annual crops | x | | | | |
| | | | | 2.4.4.02.3 SAF of other oak species with irrigated annual crops | x | | | | |
| | | | | 2.4.4.02.4 SAF of other species with irrigated annual crops | x | | | | |
| | | | | 2.4.4.02.5 SAF mixed cork and evergreen oak with irrigated annual crops | x | | | | |
| | | | | 2.4.4.02.6 SAF other mixed formations with non-irrigated annual crops | x | | | | |
| | | | 2.4.4.03 SAF with pastures/grasslands | 2.4.4.03.1 SAF cork oak and pastures | x | | | | |
| | | | | 2.4.4.03.2 SAF of evergreen and pastures | x | | | | |
| | | | | 2.4.4.03.3 SAF of other oak species and pastures | x | | | | |
| | | | | 2.4.4.03.4 SAF other species and pastures | x | | | | |
| | | | | 2.4.4.03.5 SAF mixed cork and evergreen oak trees and pastures | x | | | | |
| | | | | 2.4.4.03.6 SAF other mixed species and pastures | x | | | | |
| | | | 2.4.4.04 SAF with permanent crops | 2.4.4.04.1 SAF of cork oak and permanent crops | x | | | | |
| | | | | 2.4.4.04.2 SAF of evergreen oak and pastures | x | | | | |
| | | | | 2.4.4.04.3 SAF other oak species with permanent crops | x | | | | |
| | | | | 2.4.4.04.4 SAF other species with permanent crops | x | | | | |
| | | | | 2.4.4.04.5 SAF mixed cork and evergreen oak with permanent pastures | x | | | | |
| | | | | 2.4.4.04.6 SAF other mixed formations with permanent crops | x | | | | |
| 3 Forests and semi-natural areas | 3.1 Forests | 3.1.1 Broadleaved forests | 3.1.1.01 Pure broadleaved forests | 3.1.1.01.1 Forests dominated by the cork oak | | x | | x | x |
| | | | | 3.1.1.01.2 Forests dominated by the evergreen oak | | x | | x | x |
| | | | | 3.1.1.01.3 Forests dominated by other cork species | | x | | x | x |
| | | | | 3.1.1.01.4 Forests dominated by the sweet chestnut | | x | | | x |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 3.1.1.01.5 Forests dominated by the bluegum | | x | x | | |
| | | | | 3.1.1.01.6 Forests dominated by exotic tree species | | x | x | | |
| | | | | 3.1.1.01.7 Forests dominated by other brodleaved species | | x | | | x |
| | | | 3.1.1.02 Mixed broadleaved forests | 3.1.1.02.1 Forests dominated by the cork oak and other broadleaved species | | x | | x | x |
| | | | | 3.1.1.02.2 Forests dominated by the evergreen oak and other broadleaved species | | x | | x | x |
| | | | | 3.1.1.02.3 Forests dominated by other oak trees and other broadleaved species | | x | | x | x |
| | | | | 3.1.1.02.4 Forests dominated by the sweet chestnut and other broadleaved species | | x | | | x |
| | | | | 3.1.1.02.5 Forests dominated by the bluegum and other broadleaved species | | x | x | | |
| | | | | 3.1.1.02.6 Forests dominated by broadleaved exotic species and other broadleaved species | | x | x | | |
| | | | | 3.1.1.02.7 Forests dominated by broadleaved forests with other broadleaved species | | x | | | x |
| | | 3.1.2 Coniferous forests | 3.1.2.01 Pure coniferous forests | 3.1.2.01.1 Forests dominated by the maritime pine | | x | x | | |
| | | | | 3.1.2.01.2 Forests dominated by the stone pine | | x | | | x |
| | | | | 3.1.2.01.3 Forests dominated by other coniferous trees | | x | | | x |
| | | | 3.1.2.02 Mixed coniferous forests | 3.1.2.02.1 Forests dominated by the maritime pine with other coniferous species | | x | x | | |
| | | | | 3.1.2.02.2 Forests dominated by the stone pine with other coniferous species | | x | | | x |
| | | | | 3.1.2.02.3 Forests dominated by other coniferous trees with other coniferous species | | x | | | x |
| | | 3.1.3 Mixed forests | 3.1.3.01 Mixed broadleaved forests with coniferous species | 3.1.3.01.1 Forests dominated by the cork oak with coniferous species | | x | | x | x |
| | | | | 3.1.3.01.2 Forests dominated by the evergreen oak with coniferous species | | x | | x | x |
| | | | | 3.1.3.01.3 Forests dominated by other oak species bwith coniferous species | | x | | x | x |
| | | | | 3.1.3.01.4 Forests dominated by the sweet | | x | | | x |

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|---|---|---|---|---|---|---|---|---|---|
| | | | | chestnut with coniferous species | | | | | |
| | | | | 3.1.3.01.5 Forests dominated by the bluegum with coniferous species | | x | x | | |
| | | | | 3.1.3.01.6 Forests dominated exotic broadleaved species with coniferous species | | x | x | | |
| | | | | 3.1.3.01.7 Forests dominated by other broadleaved trees with coniferous species | | x | | | x |
| | | | | 3.1.3.01.8 Mixed forests dominated by broadleaved and coniferous tree species | | x | | | x |
| | | | 3.1.3.02 Mixed coniferous trees with broadleaved species | 3.1.3.02.1 Forests dominated by the maritime pine and other coniferous tree species | | x | x | | |
| | | | | 3.1.3.02.2 Forests dominated by the stone pine and other coniferous tree species | | x | | | x |
| | | | | 3.1.3.02.3 Forests dominated by other coniferous trees and other coniferous species | | x | | | x |
| | | | | 3.1.3.02.4 Mixed forests of coniferous tree species | | x | | | x |
| | 3.2 Open forests, scrub and/or herbaceous vegetation | 3.2.1 Natural herbaceous vegetation | 3.2.1.01 Natural herbaceous vegetation | 3.2.1.01.1 Natural herbaceous vegetation | | x* | x | | |
| | | 3.2.2 Heathlands | 3.2.2.01 Dense heathlands | 3.2.2.01.1 Dense heathlands | | x* | x | | |
| | | | 3.2.2.02 Sparse heathlands | 3.2.2.02.1 Sparse heathlands | | x* | x | | |
| | | 3.2.3 Sclerophyllous vegetation | 3.2.3.01 Sclerophyllous dense vegetation | 3.2.3.01.1 Sclerophyllous dense vegetation | | x* | x | | |
| | | | 3.2.3.02 Sclerophyllous sparse vegetation | 3.2.3.02.1 Sclerophyllous sparse vegetation | | x* | x | | |
| | | 3.2.4 Open forests and new plantations | 3.2.4.01 Open forests dominated by broaleaved trees | 3.2.4.01.1 Open forests dominated by the cork oak | | x | | x | x |
| | | | | 3.2.4.01.2 Open forests dominated by the evergreen oak | | x | | x | x |
| | | | | 3.2.4.01.3 Open forests dominated by other oak trees | | x | | x | x |
| | | | | 3.2.4.01.4 Open forests dominated by the sweet chestnut | | x | | | x |
| | | | | 3.2.4.01.5 Open forests dominated by the bluegum | | x | x | | |
| | | | | 3.2.4.01.6 Open forests dominated by broaleaved exotic trees | | x | x | | |
| | | | | 3.2.4.01.7 Open forests dominated by other broadleaved trees | | x | | | x |
| | | | 3.2.4.02 Mixed open forests with broaleaved trees | 3.2.4.02.1 Open forests dominated by the cork oak with broadleaved forests | | x | | x | x |
| | | | | 3.2.4.02.2 Open forests dominated by the evergreen oak with broadleaved forests | | x | | x | x |

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|---|---|---|---|---|---|---|---|---|---|
| | | | | 3.2.4.02.3 Open forests dominated by other oak trees with broadleaved forests | | x | | x | x |
| | | | | 3.2.4.02.4 Open forests dominated by chestnut with broadleaved forests | | x | | | x |
| | | | | 3.2.4.02.5 Open forests dominated by the bluegum with broadleaved forests | | x | x | | |
| | | | | 3.2.4.02.6 Open forests dominated by exotic trees with broadleaved forests | | x | x | | |
| | | | | 3.2.4.02.7 Open forests dominated by other broadleaved trees with broadleaved forests | | x | | | x |
| | | | 3.2.4.03 Open forests dominated by conifeours trees | 3.2.4.03.1 Open forests dominated by maritime pine | | x | x | | |
| | | | | 3.2.4.03.2 Open forests dominated by stone pine | | x | | | x |
| | | | | 3.2.4.03.3 Open forests dominated by other coniferous trees | | x | | | x |
| | | | 3.2.4.04 Mixed open forests with coniferours trees | 3.2.4.04.1 Open forests of maritime pine and coniferous trees | | x | x | | |
| | | | | 3.2.4.04.2 Open forests of stone pine and coniferous trees | | x | | | x |
| | | | | 3.2.4.04.3 Open forests of other coniferous trees and coniferous trees | | x | | | x |
| | | | 3.2.4.05 Open forests dominated by both broaleaved and coniferous trees | 3.2.4.05.1 Open forests of cork oak and coniferous trees | | x | | x | x |
| | | | | 3.2.4.05.2 Open forests of evergreen oak and coniferous trees | | x | | x | x |
| | | | | 3.2.4.05.3 Open forests of other oak trees and coniferous trees | | x | | x | x |
| | | | | 3.2.4.05.4 Open forests of sweet chestnut and coniferous trees | | x | | | x |
| | | | | 3.2.4.05.5 Open forests of bluegum and coniferous trees | | x | x | | |
| | | | | 3.2.4.05.6 Open forests of exotic with coniferours trees | | x | x | | |
| | | | | 3.2.4.05.7 Open forests of other broadleaved and conifeours trees | | x | | | x |
| | | | | 3.2.4.05.8 Open forests of mixed broadleaved and conifeours trees | | x | | | x |
| | | | 3.2.4.06 Open forests dominated by both coniferous and broadleaved trees | 3.2.4.06.1 Open forests of stone pine and broadleaved trees | | x | x | | |
| | | | | 3.2.4.06.2 Open forests of maritime pine and broadleaved trees | | x | | | x |
| | | | | 3.2.4.06.3 Open forests of other conifers and broadleaved trees | | x | | | x |
| | | | | 3.2.4.06.4 Open forests of mixed conifers and broadleaved trees | | x | | | x |
| | | | 3.2.4.07 Other woody vegetation | 3.2.4.07.1 Other woody formation | | x | | | x |
| | | | | 3.2.4.08.1 Rare cuts | | x | x | | |

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| | | | 3.2.4.08 Rare cuts and new plantations | 3.2.4.08.2 New plantations | | x | x | | |
| | | | 3.2.4.09 Forest nurseries | 3.2.4.09.1 Forest nurseries | | x | x | | |
| | | | 3.2.4.10 Steels and/or firebreaks | 3.2.4.10.1 Steels and/or firebreaks | x | | | | |
| | 3.3 Open spaces with litle or no vegetation | 3.3.1 Beaches, dunes, sands | 3.3.1.01 Inland beaches, dunes, sands | 3.3.1.01.1 Inland beaches, dunes, sands | x | | | | |
| | | | 3.3.1.02 Coastal beaches, dunes, sands | 3.3.1.02.1 Coastal beaches, dunes, sands | x | | | | |
| | | 3.3.2 Bare rock | 3.3.2.01 Bare rock | 3.3.2.01.1 Bare rock | x | | | | |
| | | 3.3.3 Sparsely vegetated areas | 3.3.3.01 Sparsely vegetated areas | 3.3.3.01.1 Sparsely vegetated areas | x | | | | |
| | | 3.3.4 Burnt areas | 3.3.4.01 Burnt areas | 3.3.4.01.1 Burnt areas | x | | | | |
| 4 Wetlands | 4.1 Inland wetlands | 4.1.1 Inland marshes | 4.1.1.01 Inland marshes | 4.1.1.01.1 Inland marshes | x | | | | |
| | | 4.1.2 Peat bogs | 4.1.2.01 Peat bogs | 4.1.2.01.1 Peat bogs | x | | | | |
| | 4.2 Maritime wetlands | 4.2.1 Salt marshes | 4.2.1.01 Salt marshes | 4.2.1.01.1 Salt marshes | x | | | | |
| | | 4.2.2 Salines | 4.2.2.01 Salines | 4.2.2.01.1 Salines | x | | | | |
| | | | 4.2.2.02 Coastal aquaculture | 4.2.2.02.1 Coastal aquaculture | x | | | | |
| | | 4.2.3 Intertidal flats | 4.2.3.01 Intertidal flats | 4.2.3.01.1 Intertidal flats | x | | | | |
| 5 Water bodies | 5.1 Inland waters | 5.1.1 Water courses | 5.1.1.01 Natural water courses | 5.1.1.01.1 Natural water courses | x | | | | |
| | | | 5.1.1.02 Artificial chanals | 5.1.1.02.1 Artificial chanals | x | | | | |
| | | 5.1.2 Water bodies | 5.1.2.01 Inland lakes and lagoons | 5.1.2.01.1 Artificial Inland lakes and lagoons | x | | | | |
| | | | | 5.1.2.01.2 Natural Inland lakes and lagoons | x | | | | |
| | | | 5.1.2.02 Dam reservoirs | 5.1.2.02.1 Dam reservoirs | x | | | | |
| | | | 5.1.2.03 Other artificial water bodies | 5.1.2.03.1 Dam/ weir reservoirs | x | | | | |
| | | | | 5.1.2.03.2 Charcas | x | | | | |
| | | | | 5.1.2.03.3 Inland aquaculture | x | | | | |
| | 5.2 Marine waters | 5.2.1 Coastal lagoons | 5.2.1.01 Coastal lagoons | 5.2.1.01.1 Coastal lagoons | x | | | | |
| | | 5.2.2 Estuaries | 5.2.2.01 Estuaries | 5.2.2.01.1 Estuaries | x | | | | |
| | | 5.2.3 Sea and ocean | 5.2.3.01 Sea and ocean | 5.2.3.01.1 Sea and ocean | x | | | | |